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STRUCTURAL GEOLOGY AND STRATIGRAPHY OF THE COAL-BEARING AND ADJACENT STRATA NEAR MOUNTAIN PARK, ALBERTA

by

© WARD E. KILBY

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE
IN
GEOLOGY

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA
FALL, 1978

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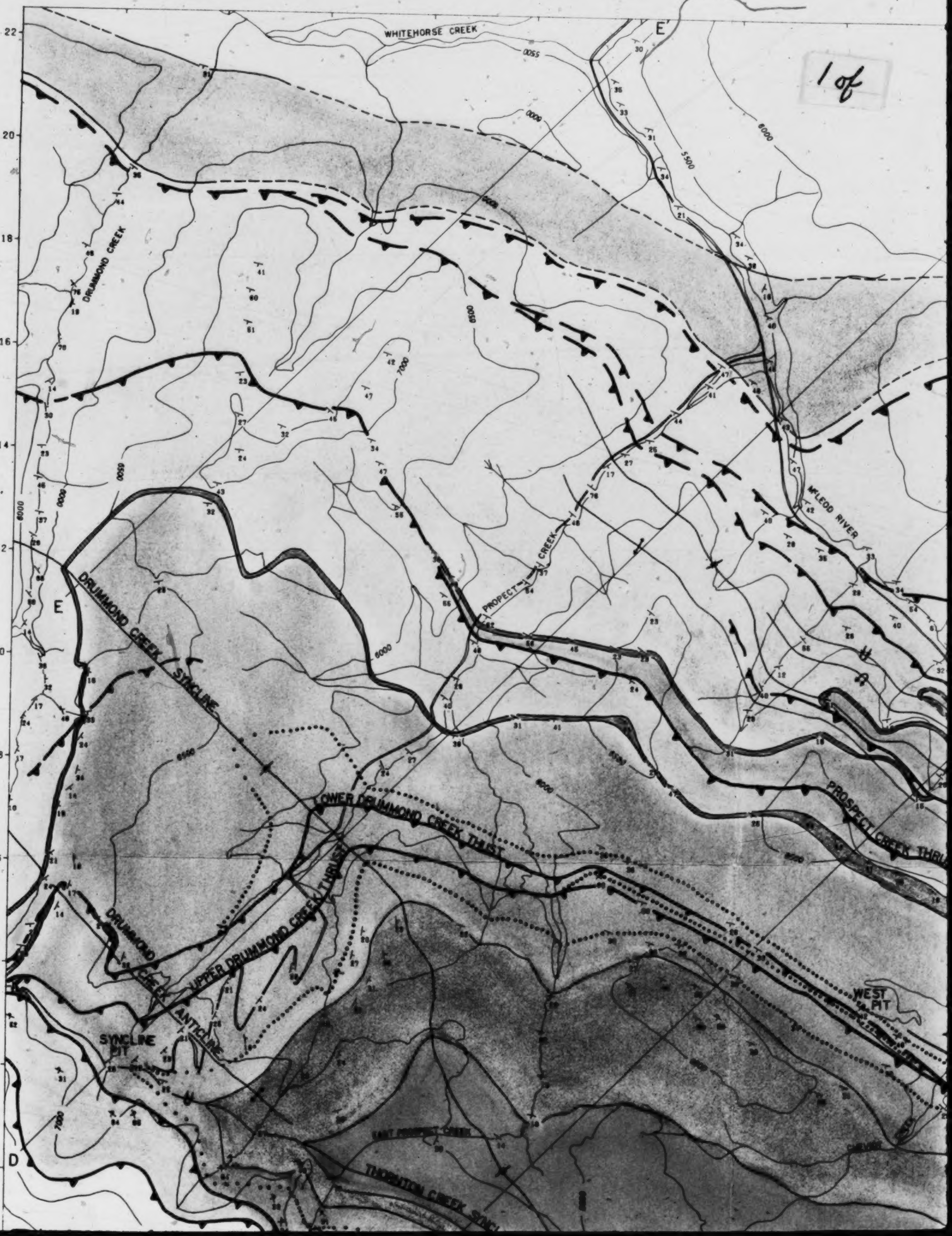
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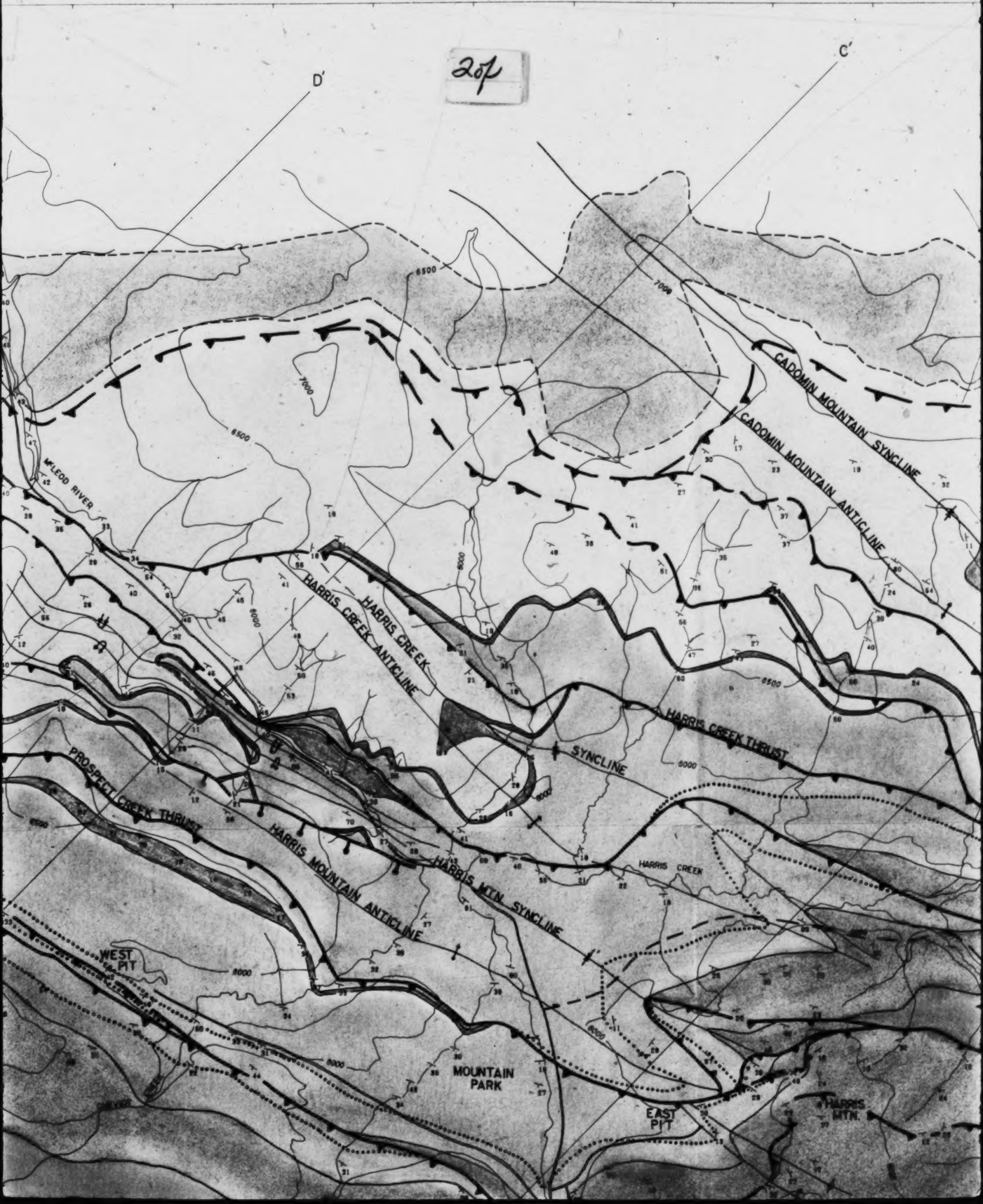

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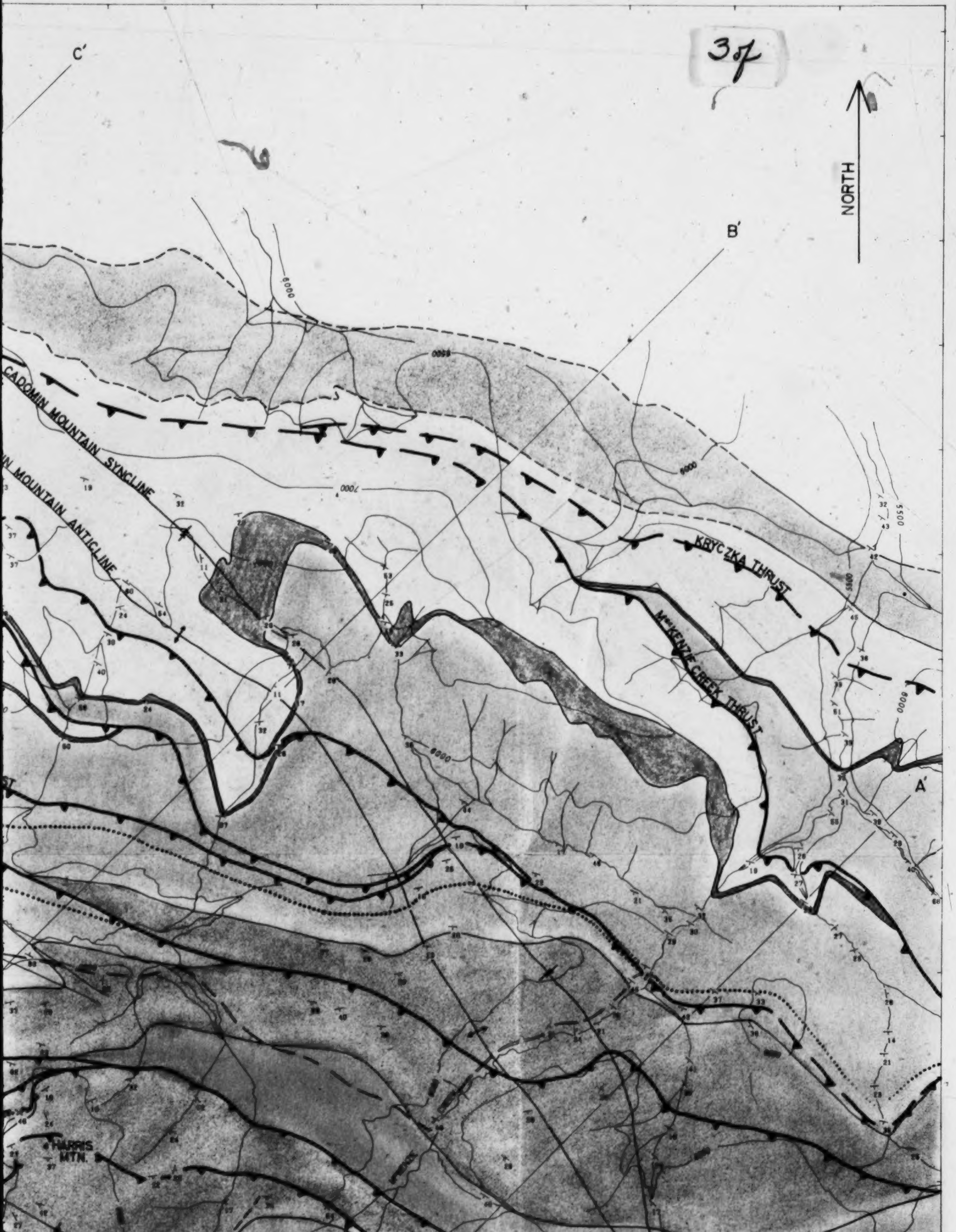
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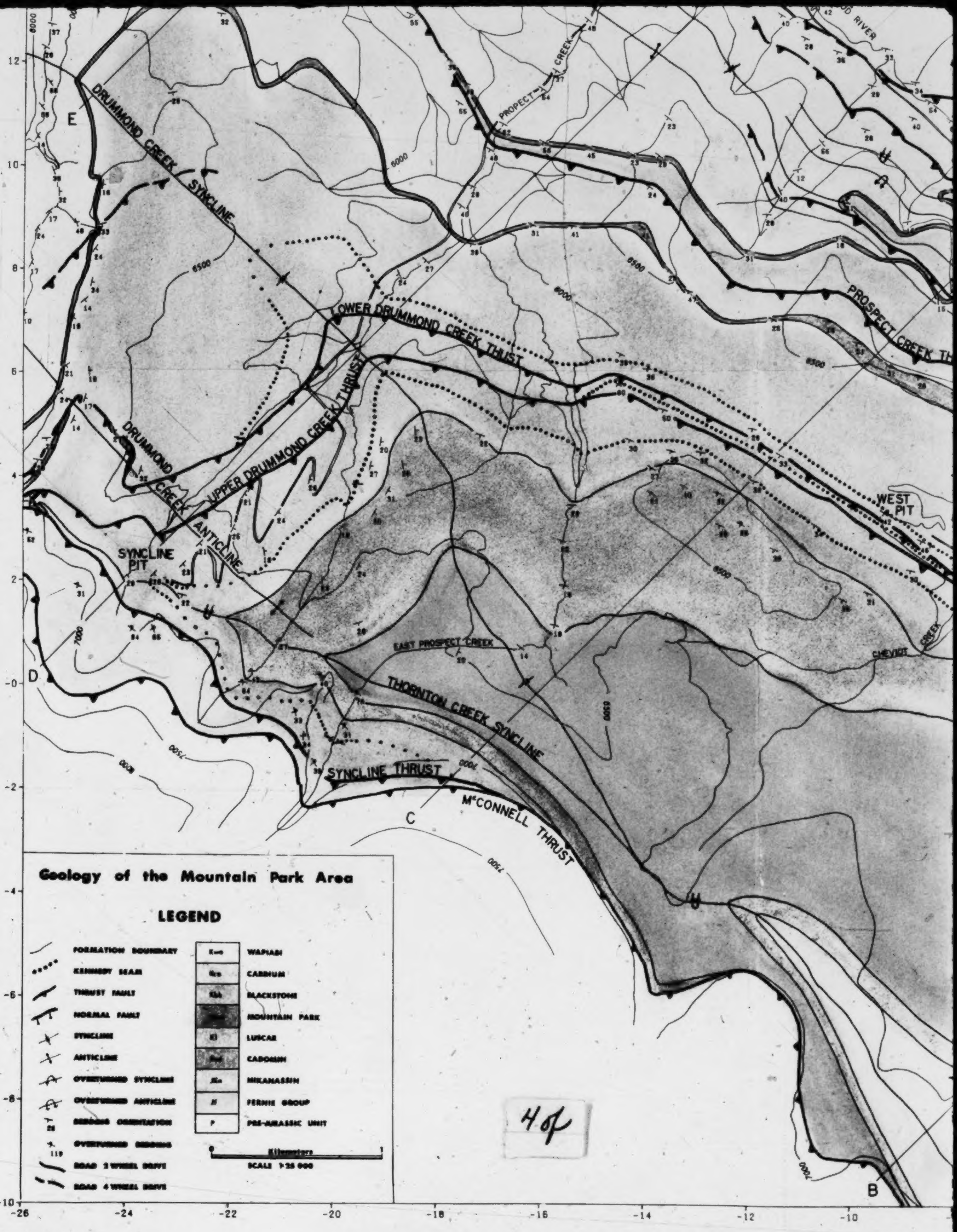
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28
BEDDING ORIENTATION
119
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ROAD 2 WHEEL DRIVE
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Geology of the Mountain Park Area

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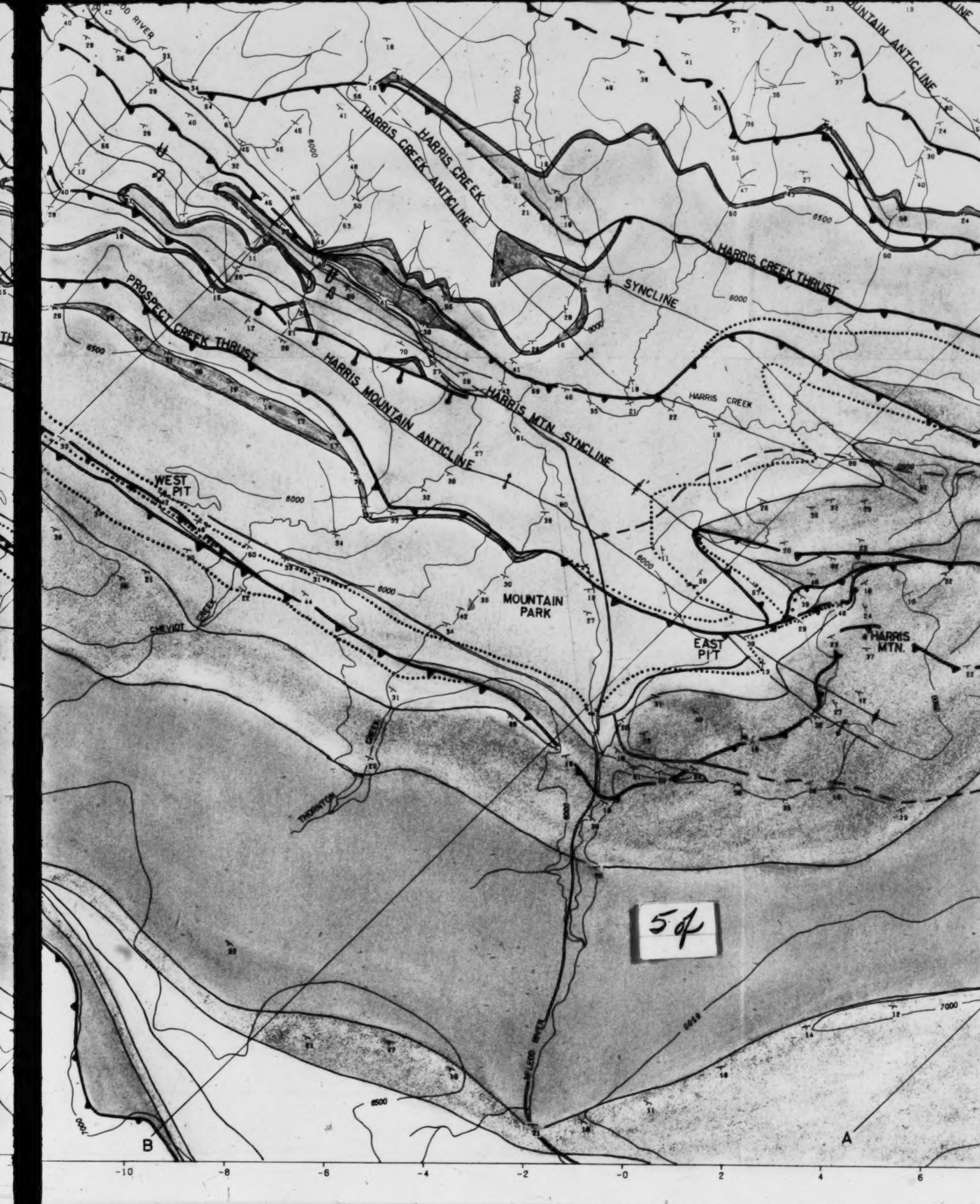
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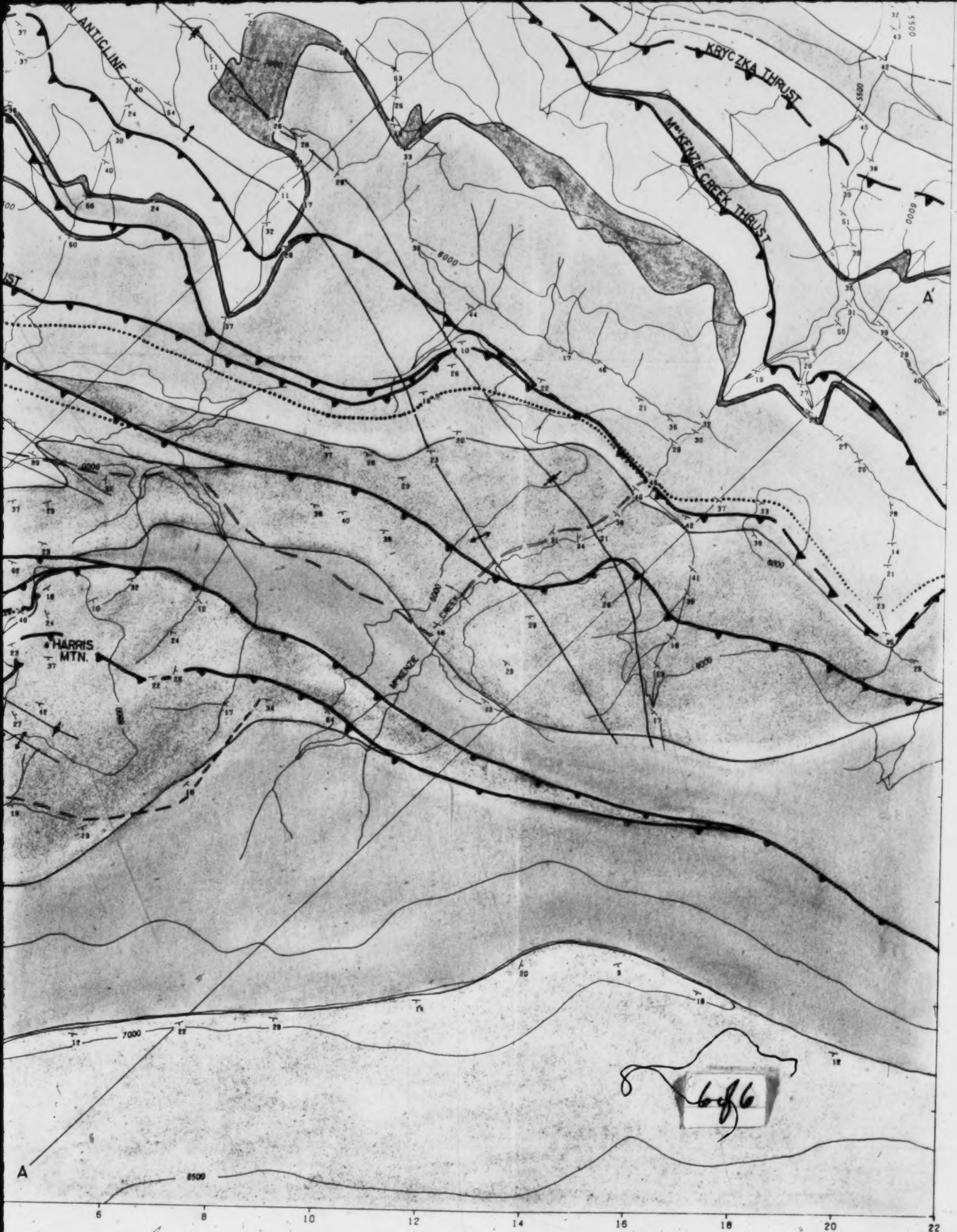
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6 of 6

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Structure and Stratigraphy of the Coal-bearing and Adjacent Strata near Mountain Park, Alberta

submitted by Ward E. Kilby

in partial fulfilment of the requirements for the degree of Master of Science in Geology.

H.A.K. Charlesworth
Supervisor

T. Patching

Date July 28, 1978

ABSTRACT

In a 140 sq km area of the Nikanassin thrust sheet near Mountain Park, Alberta, over 800 outcrops and 450 borehole logs were examined. Many of the positional, stratigraphic and orientation data thereby accumulated were stored, retrieved and processed using the computer. Computerized techniques were used to plot outcrop maps, establish cylindrical structural domains, calculated fold axes, rotate domains, and construct single and composite down-plunge plots from which structural cross sections and profiles could be drawn.

The coal-bearing Lower Cretaceous Luscar Formation is probably only 340 m thick and contains only four seams thicker than 1 m. The 11 m Kennedy seam has been correlated with seams along 350 km of the Rocky Mountains from Nordegg, Alberta to Mount Belcourt in northeastern British Columbia. The Lower Cretaceous Mountain Park Formation, 200 m thick, can be distinquished from the underlying Luscar on the basis of its consistent green colour, the occurence of conglomerates and its greater resistance to erosion.

Structural mapping and the use of down-plunge projections have led to the recognition of five hither to unrecognized or only incompletely identified thrust faults.

These cut up section to the northeast at angles of about 5° and have displacements of 1 to 2 km. Traced down section to the northwest, these faults appear to represent splays from the McConnell and Miette thrusts. Up section to the southeast they flatten and merge in the Upper Cretaceous Blackstone Formation. Folding in the thrust sheets appears to have resulted from the stepping of thrusts from one stratigraphic horizon to another.

ACKNOWLEDGEMENTS

The author wishes to thank Consolidation Coal Company of Canada for providing access to all their field and borehole data in the study area. Without their cooperation this study would not have been possible. Much of the study was carried out while the author was a graduate teaching assistant in the Department of Geology. National Research Council of Canada and Geological Survey of Canada grants in aid of research to Dr. Henry Charlesworth helped defray certain expenses related to the project. Geologists of Consolidation Coal Company of Canada and Luscar Limited provided information and encouragement with the regional seam correlation. The author also wishes to acknowledge the guidance and encouragement of his supervisor Dr. Charlesworth. Dr. Chris Gold, Mr. Dave Flint and Mr. Bruce Vincent provided invaluable help with computer related problems. Mr. Ron Swaren and Mr. Scott Anderson worked with the author in the field and Miss Kathy Berndt helped digitize map data and verify data files.

TABLE OF CONTENTS

CHAPTER PAGE

INTRODUCTION 1

COLLECTION AND PROCESSING OF STRUCTURAL DATA 7
- Data Collection 7
  - Field Data 7
  - Borehole Data 12
  - Mine Data 14
- Data Storage 14
- Data Retrieval 19
- Data Processing 20
  - Means and Mesoscopic Fold axes at Outcrops 21
  - Establishment of Potential Domains 22
  - Mesoscopic Fold Axes 25
  - Testing Cylindricity 26
  - Structural Cross Sections and Profiles 29
  - Map Construction 32
  - Orientation Diagrams 34
  - Thickness Determination 34

STRATIGRAPHY 36
- Pre-Jurassic (undivided) 36
- Fernie Group 37
- Nikanassin Formation 38
- Cadomin Formation 39
- Luscar Formation 41
- Mountain Park Formation 54
- Blackstone Formation 55
- Cardium Formation 56
- Wapiabi Formation 56

STRUCTURE 57
- Drummond Creek thrust sheet 59
  - Drummond Creek thrust 59
  - The thrust sheet 62
- Prospect Creek thrust sheet 65
  - Prospect Creek thrust 65
  - The thrust sheet 66
- Harris Creek thrust sheet 68
  - Harris Creek thrust 70
  - The thrust sheet 70
- MacKenzie Creek thrust sheet 73
  - MacKenzie Creek thrust 73
  - The thrust sheet 74
- Kryczka thrust sheet 76

TABLE OF CONTENTS continued

Kryczka thrust 76
The thrust sheet 76
Mesoscopic Structures 78
Discussion 84

CONCLUSIONS 85

REFERENCES 86

***

APPENDIX 1 FORMATS AND PARTIAL LISTINGS OF DATA 89

APPENDIX 2 RETRIEVAL PROGRAMS AND AR-FILE 100

APPENDIX 3 DATA PROCESSING PROGRAMS AND PROCEDURES .. 107

APPENDIX 4 DOWN-PLUNGE PLOTS OF DOMAINS 120

APPENDIX 5 STRATIGRAPHIC SECTION NEAR KENNEDY SEAM .. 152

LIST OF FIGURES

Figure		Page
1	Geological Map of the Rocky Mountain Foothills between the Athabasca and North Saskatchewan Rivers.	2
2	Field Data Sheets	10
3	Representative Borehole Logs	13
4	Horizontal Extent of Underground Mine Workings at Mountain Park.	15
5	Domain Boundaries and Fold Axes	23
6	Retrieval and Cylindricity Testing Proceedure	24
7	Domains Along Section Line D-D' Before and After Rotation.	33
8	Comparison of Luscar Sections	42
9	Kennedy Seam Structure Contour Map	44
10	Correlation Diagram	51
11	Seam Correlation Index Map	52
12	Seam Correlation Borehole Logs	53
13	Geology Map	(In Pocket)
14	Structural Cross Section	58
15	Harris Mountain Horse Profile	69
16	Mesoscopic Fold Distribution	79
17	Joint Orientations	81

LIST OF PHOTOGRAPHIC PLATES

Plate	Description	Page
1	Structural Terrace in the pre-Jurassic	37
2	Fernie Group along Drummond Creek	38
3	Nikanassin Formation along McLeod River	39
4	Nikanassin, Cadomin and Luscar Formations along Drummond Creek	40
5	Cheviot Seam and Possible Moosebar Formation Equivalent	43
6	Kennedy Seam Outcrop 1 km East of MacKenzie Creek	45
7	Kennedy Seam Outcrop 2 km East of MacKenzie Creek	46
8	Kennedy Seam in West Pit	46
9	Overview of Western Portion of Study Area	54
10	Cardium Formation in Thornton Creek Syncline and McConnell thrust sheet	55
11	Syncline Pit, Syncline Thrust and McConnell Thrust	63
12	Adit in Overturned Kennedy Seam	64
13	Jointed Cardium Sandstone	80
14	Kennedy Exposure in East Pit	82
15	Joints in East Pit	82

INTRODUCTION

Coal occurs at two stratigraphic levels in the Rocky Mountains of west-central Alberta, namely in the Lower Cretaceous Luscar Formation, where it is of metallurgical grade, and as thermal coal in the Brazeau (Saunders or Wapiti) Group of Late Cretaceous to Paleocene age. Little has been published on the structural style of either set of coal measures. The purpose of this study was to determine as much as possible of the macroscopic structure of the older set of coal measures and adjacent strata in a 140 sq km area of the Foothills near the former coal mining community of Mountain Park (Fig. 1). More precisely, the objectives were to (1) produce a detailed geological map and cross section of the area, (2) use computer techniques to store, retrieve and process the available surface and subsurface geological data and (3) examine the Luscar stratigraphic section and its relationship to surrounding areas containing Luscar strata. It was hoped that the study would (a) improve the efficiency of coal exploitation in the Mountain Park area, (b) be a case history of interest to the coal mining industry elsewhere in Alberta and British Columbia, (c) illustrate the ease and power of computer-based numerical techniques in structural analysis, (d) contribute to our knowledge of Rocky Mountain geology.

Mountain Park, about 320 km west of Edmonton, is

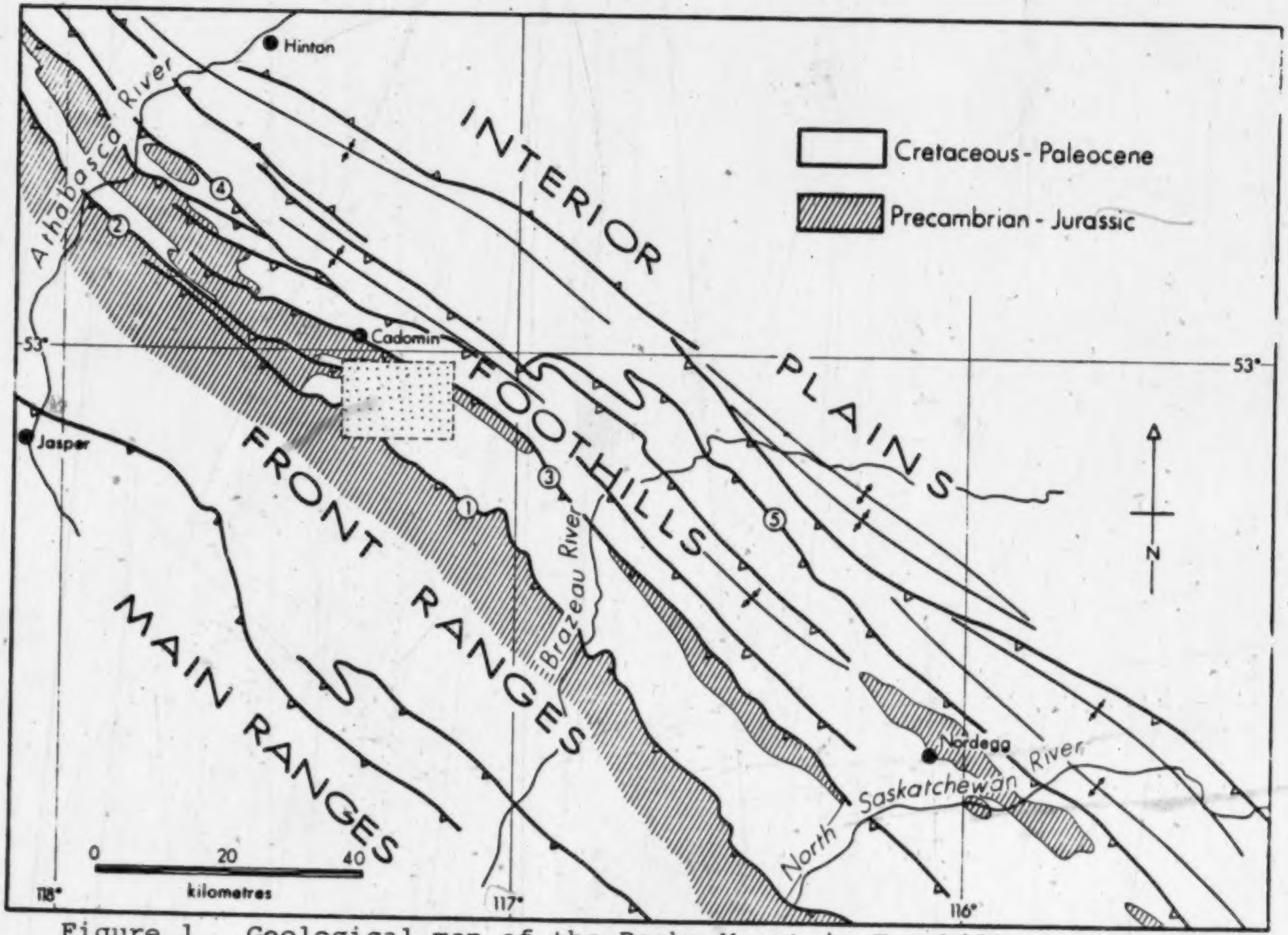

INTERIOR
PLAINS
FOOTHILLS
FRONT RANGES
MAIN RANGES
Cretaceous - Paleocene
Precambrian - Jurassic
Hinton
Cadomin
Jasper
Nordegg
Athabasca River
Brazeau River
North Saskatchewan River
N
53°
53°
118°
117°
116°
0
20
40
kilometres
1
2
3
4
5

Figure 1. Geological map of the Rocky Mountain Foothills between the Athabasca and North Saskatchewan Rivers showing thesis area stippled. (1) McConnell thrust, (2) Miette thrust, (3) Nikanassin-Bighorn thrust, (4) Folding Mountain thrust and (5) Brazeau thrust.

readily accessible by road from Edson and Hinton via Cadomin or from Nordegg by means of the Forestry Trunk and Grave Flats Roads. The Canadian National Railway's Coal Branch at present ends at Cadomin, 13 km north of Mountain Park, although it formerly extended as far as Mountain Park itself. Within the study area there are numerous roads ranging from those suitable for cars to those accessible only to four-wheel drive vehicles. Although the nearest accommodation is at Hinton, 65 km away, there are public campgrounds near the study area on Whitehorse Creek and the Cardinal River.

Elevations range from 1 675 m in the valley floors to in excess of 2 740 m on the bordering peaks of the Rocky Mountain Front Ranges. Local topographic relief is dependent upon rock type: as a rule it is low on the recessive Fernie, Luscar and Blackstone Formations and somewhat greater on the more resistant pre-Jurassic, Nikanassin, Cadomin and Mountain Park Formations.

Elevation controls the type of vegetation found. Pine and spruce montane forests at lower elevations pass upwards into sub-alpine vegetation and finally into alpine tundra. Forest once covered most of the study area. The effects of a forest fire which narrowly missed destroying Mountain Park in 1913 are still recognizable, with bleached stumps and stunted regrowth occupying the razed sections. Disjunct alpine-tundra species are under study in the area by graduate students from the Department of Botany (see e.g. Mortimer 1978).

The study area lies within the Mountain Park map-sheet which was mapped by the Geological Survey of Canada in 1924 and 1925 (MacKay 1929). No accompanying report was ever published, and the most comprehensive written work on the area is MacKay (1930). Earlier regional studies which embrace the Mountain Park area include those by Dowling (1910,1915), Stewart (1917) and Allan and Rutherford (1924). Recent statigraphic, paleontological and sedimentological studies involving strata within the thesis area include those by Kryczka (1959), Stott (1963,1968,1974), Mellon (1964,1966), Hacquebard and Donaldson (1974), McLean (1977) and Gibson (1978).

The development of the coal mining industry in the Rocky Mountains of west-central Alberta coincided with the construction of the Grand Trunk Pacific and Canadian Northern Railways in the early part of the century. Within the study area John Gregg in 1909 discovered and staked a coal showing "... at the base of a mountain later known as Mount Cheviot ..." (Ross 1974 p. 10), probably along the McLeod River in the immediate vicinity of the old townsite of Mountain Park. By the summer of 1910 Gregg had succeeded in interesting a British company, represented by a mining engineer called Robert Thornton, in his property. Thornton returned in 1911 to develop a mine on behalf of Mountain Park Collieries. Mining began in 1912 and continued uninterruptedly until 1950 when operations ceased owing to lack of markets. Altogether a total of six million tonne of coal was extracted in the area. The town of Mountain Park has since been dismantled and all that remains are the cemetery, several concrete foundations and the old mine pits with their spoil piles. Some details about the history of the mine and the town are to be found in Ross (1974).

The last decade has witnessed renewed interest in Alberta coal. At the same time there has been increasing concern about the effect that coal mining can have on the environment, and many areas in the Rocky Mountains and Plains cannot at present be exploited for coal as a result of legislation passed by the Government of Alberta. The Mountain Park area, however, lies in Category 4 of the Alberta Coal Development Policy in which "Exploration [and] ...Development [are] permitted under normal approval procedures" (Government of Alberta 1976, p. 18). The ground underlain by coal in the Mountain Park area is leased to a consortium of Consolidation Coal Company of Canada Ltd. and Luscar Ltd. and over the past 10 to 15 years has been geologically investigated by this consortium. During four months in the summer of 1976 the author was hired by Consolidation Coal Company of Canada to map the coal bearing

Luscar Formation and contiguous formations of the area. In addition the author spent about one month mapping the adjacent formations in more detail during his days off and at the end of the field season. Approximately 14 trips to the Red Deer office of the Company were required to interpret and record the subsurface data contained in borehole logs and old mine plans. These trips were made between September and December 1976 while in full time attendance at the University of Alberta.

COLLECTION AND PROCESSING OF STRUCTURAL DATA

Data Collection

Field Data

While in the field, mapping proceeded essentially by visiting outcrops, plotting positions on aerial photographs, determining structure and stratigraphy and entering this information on field data sheets. Certain stratigraphic contacts, for example the boundaries of the Cadomin Formation, were traced on the aerial photographs using topographic features identified both in the field and on stereoscopic pairs of photographs. Data pertaining to the position of each outcrop, the orientation of bedding and the identity of the formation exposed there were transferred as soon as possible to the base map along with the traces of formational boundaries, faults and the axial surfaces of folds. Throughout the study, as understanding of the structure improved, the positions of these traces were continually adjusted.

Transportation was by means of a Ford 3/4 ton 4-wheel drive truck and two Suzuki RV125 motorcycles. This combination of vehicles greatly enhanced the work potential of the field crew.

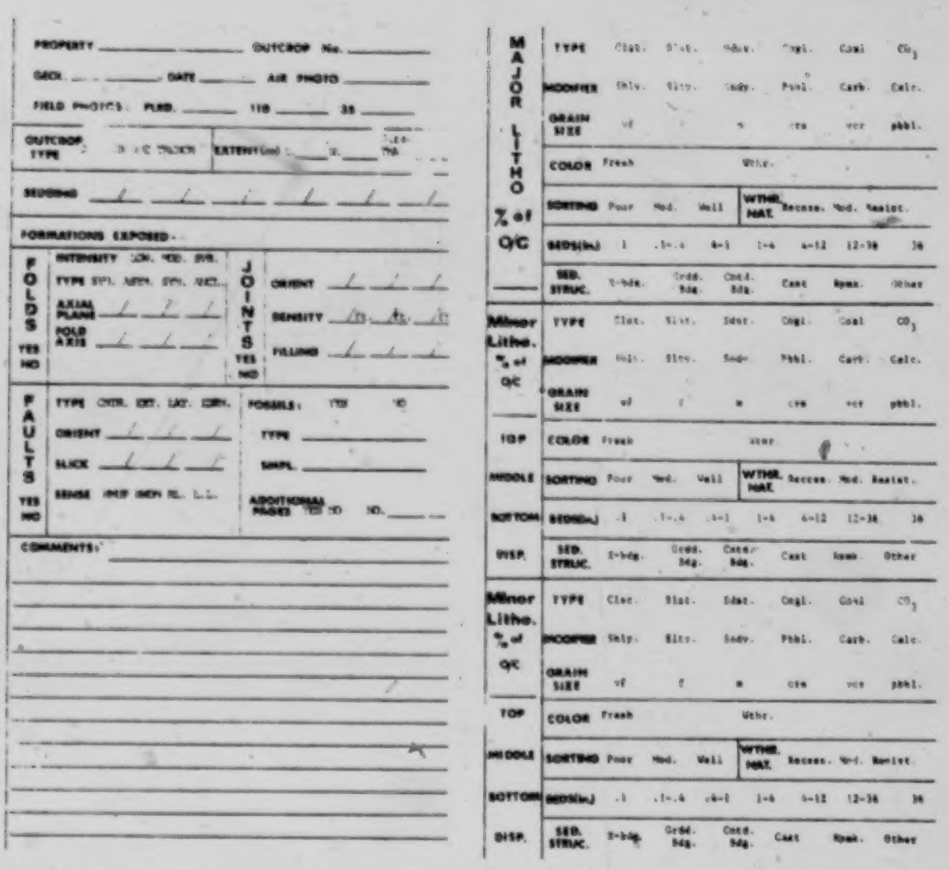
Two sets of aerial photographs were used. The first set, prepared by Co-ordinate Aerial Surveys at a scale of 1:14 400, centered on areas underlain by the Luscar Formation. A second set of photographs produced by the Alberta Department of Energy and Natural Resources at a scale of 1:21 120 provided complete coverage. Due to extensive shadows and poor contrast the latter photographs were of inferior quality and used only where absolutely necessary. A scale of 1:10 560, more amenable to field work, was obtained by enlarging the Government photographs by a factor of two.

Topographic maps for the Mountain Park area, produced by Co-ordinate Aerial Surveys, were available at two scales. The more extensive map, covering 85 sq km at a scale of 1:4 800 with 25-foot contours, covers the outcrop of the Luscar and immediately surrounding strata. The other map, covering 10 sq km at a scale of 1:1 200 with 5-foot contours, provides coverage of those areas where mining is anticipated. Beyond the limits of these accurate maps the only available topographic control was from a survey carried out from 1921 to 1924 at a scale of 1:63 360 by the National Topographic Service. The map resulting from this survey (83-C-14) published in 1924 is inaccurate at the scale of the present investigation.

Field sheets enabling all Company geologists to record lithologic and structural data uniformly, precisely and accurately were designed before the field season by the author and the staff of the Consolidation Coal Company of Canada. Although subsequently found to be too general for this study they were nonetheless of considerable benefit (Fig. 2). For structural studies the following changes to the field sheets are recommended:

1) More space be provided for orientation measurements: data entered in the existing space required extra documentation to avoid later confusion.
2) Less space be provided for folds, joints and faults: data pertaining to these structures are better recorded elsewhere, with only the fact that they are absent or present recorded on the field sheet.
3) Less space be provided for lithologic information: although undoubtedly excellent for a lithologically oriented study this section was rarely used.

Data collection and recording at the outcrop form the basis of geologic mapping and are possibly the most common source of errors in a mapping project. Therefore a system of accurate and concise collection and recording is of the utmost importance. The system used in this study was as follows.



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FIELD PHOTOS. FLSD. ________ 110 ________ 35 ________
OUTCROP TYPE [illegible] EXTENT(m) ____ × ____
BEDDING _/_ _/_ _/_ _/_ _/_ _/_
FORMATIONS EXPOSED-

FOLDS YES NO	INTENSITY LOW. MOD. SVR. TYPE SYN. ANTI. [illegible] AXIAL PLANE _/_ _/_ _/_ FOLD AXIS _/_ _/_ _/_	JOINTS YES NO	ORIENT _/_ _/_ _/_ DENSITY _/_ _/_ _/_ FILLING _/_ _/_ _/_
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MIDDLE	SORTING	Poor	Mod.	Well	WTHR. NAT.	Recess.	Mod.	Resist.
BOTTOM	BEDS(m)	.1	.1-.4	.4-1	1-4	4-12	12-36	36
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MIDDLE	SORTING	Poor	Mod.	Well	WTHR. NAT.	Recess.	Mod.	Resist.
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DISP.	SED. STRUC.	X-bdg.	Grdd. Bdg.	Cntd. Bdg.	Cast	Rpmk.	Other	

Figure 2. Field data sheet with the front shown on the left and the back on the right (original size 10x17 cm).

1) The position of the station or outcrop was recorded on the aerial photograph and a note on the accuracy of this position placed in the field notes. A small pin hole through the photograph with the appropriate label on the back provided a permanent record of the position.

2) A short lithologic description, the formation name and the reasons for assigning the strata to the formation were recorded.

3) Bedding plane orientations were measured and recorded in

degrees as dip direction and dip. Dip direction, the azimuth of the direction normal to the strike in which the strata young, can range from 0 to 359°. Dip, the angle through which the strata have apparently been rotated, can range from 0 to 180°, being greater than 90° in the case of overturned beds. The recording of orientations in the field and in all subsequent work is represented as dip direction/dip or trend/plunge for planar and linear orientations respectively. Provided no mesoscopic folding was observed at the outcrop, five bedding plane orientations were measured within 3 m of the position recorded above. When mesoscopic folding was present five or more orientations were recorded, if necessary beyond the above 3 m limit. At several outcrops two sets of measurements were recorded separately, one pertaining to mesoscopically folded and the other to uniformly oriented strata. Two types of compass were used to measure orientations. The Brunton Compass used during the first half of the field season was later replaced by a Freiberger Structural Compass. The latter was preferred for a number of reasons: (1) dip direction and dip are read directly, (2) awkwardly placed surfaces are more easily measured and (3) measurements are collected more quickly. As well as bedding, other structures such as joints, faults and slickensides were recorded in a similar manner.

4) The outcrop was sketched or photographed if warranted. A

Polaroid Land, 110 Instamatic and 135 single lens reflex camera were used to photograph significant views and outcrops. Polaroid pictures reduced the need tc sketch outcrops.

5) The setting of the outcrop and how it fitted into the larger structural picture were briefly described.

Borehole Data

Subsurface data from 350 boreholes were available in the form of driller's, natural gamma and resistivity logs. Various combinations of these logs were available to the author. Characteristic traces of certain coal seams provided excellent marker horizons throughout the area (Fig. 3). Upon familiarization with the traces of specific horizons it was a relatively simple matter to record the down hole distance and from it and the borehole orientations to calculate the coordinates of each horizon intersection. Because the purpose of the boreholes was to determine the position of the Kennedy coal seam in the Luscar Formation, the borehole data are restricted to that part of the section immediately above and below this seam.

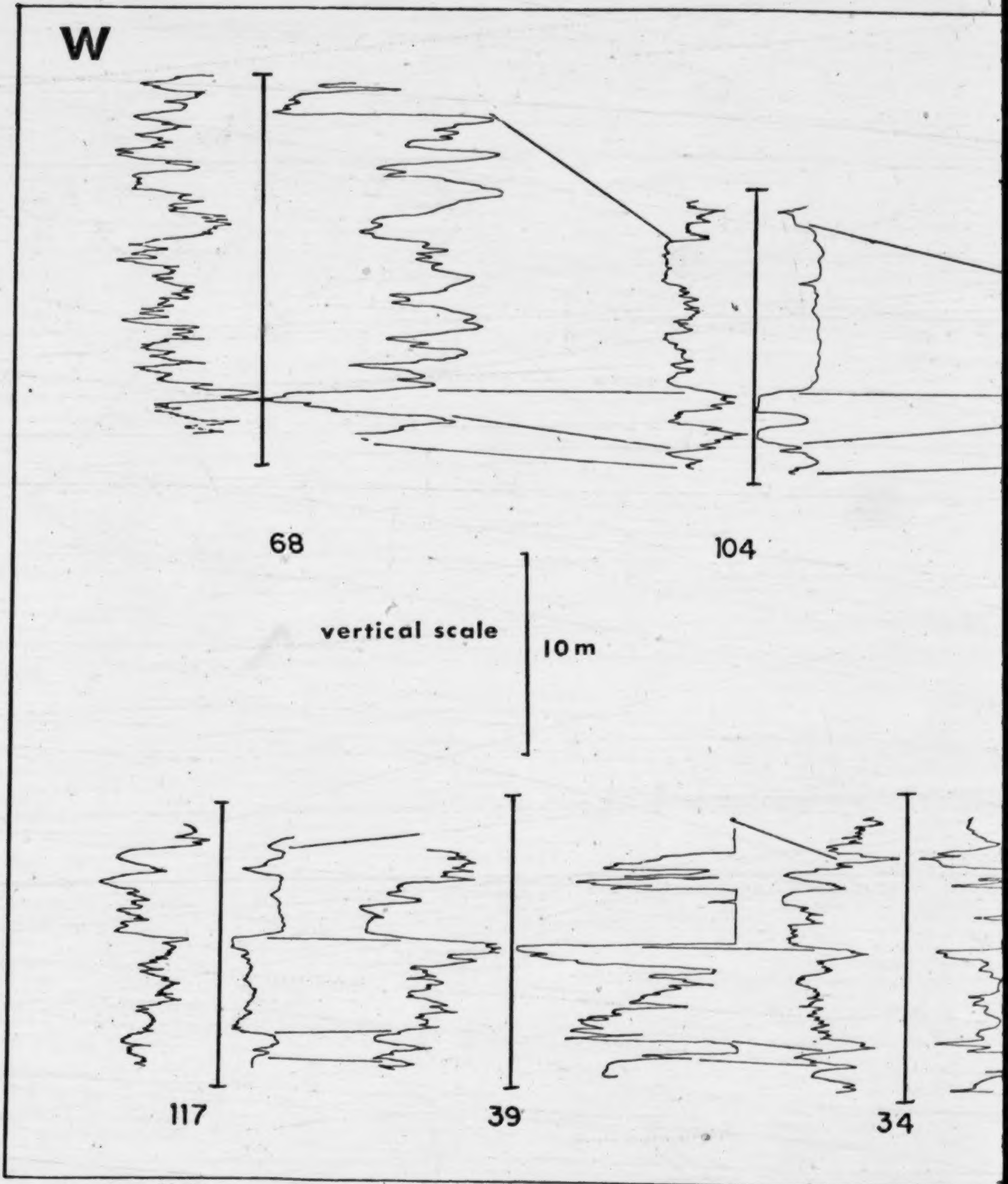
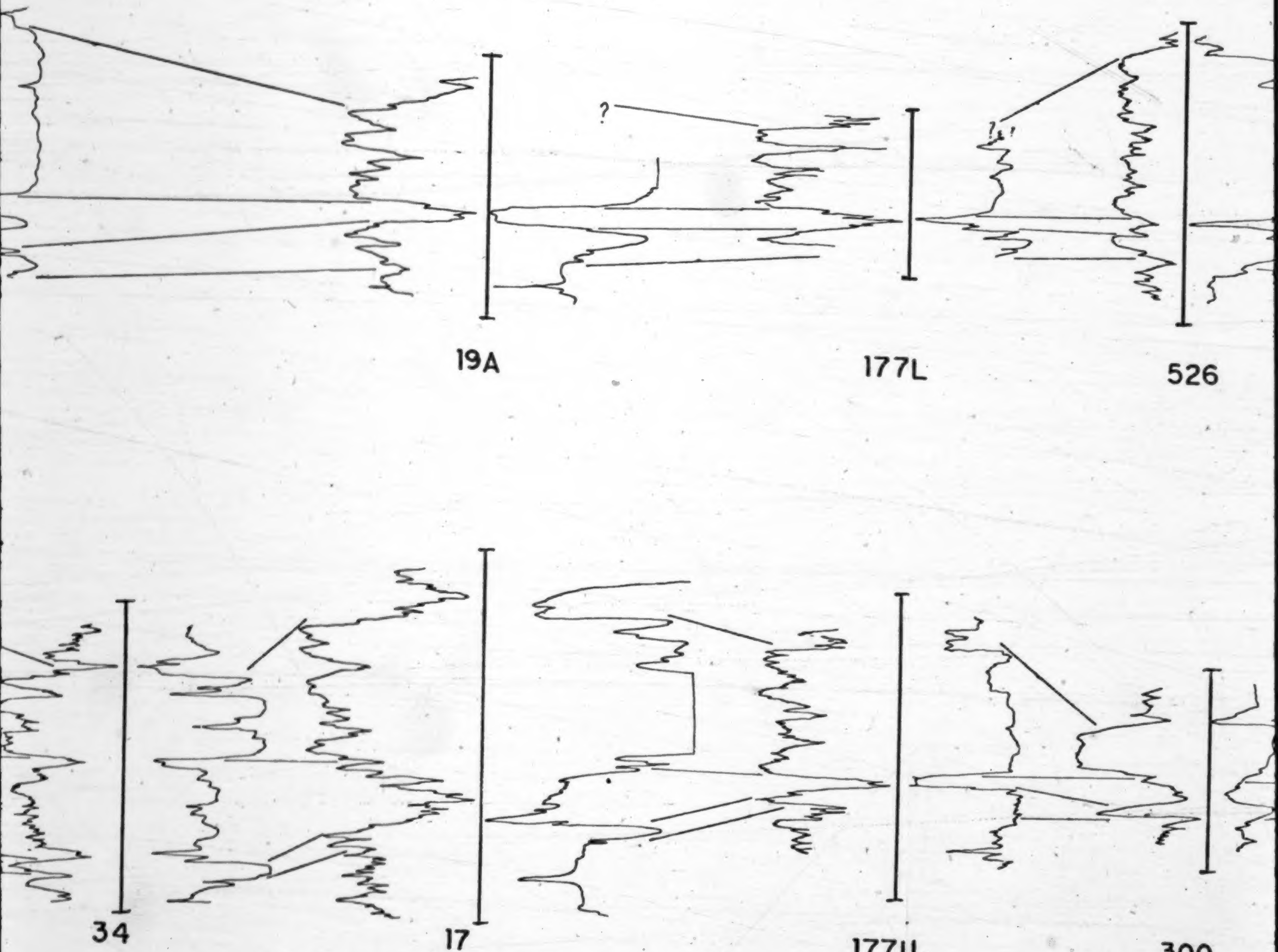


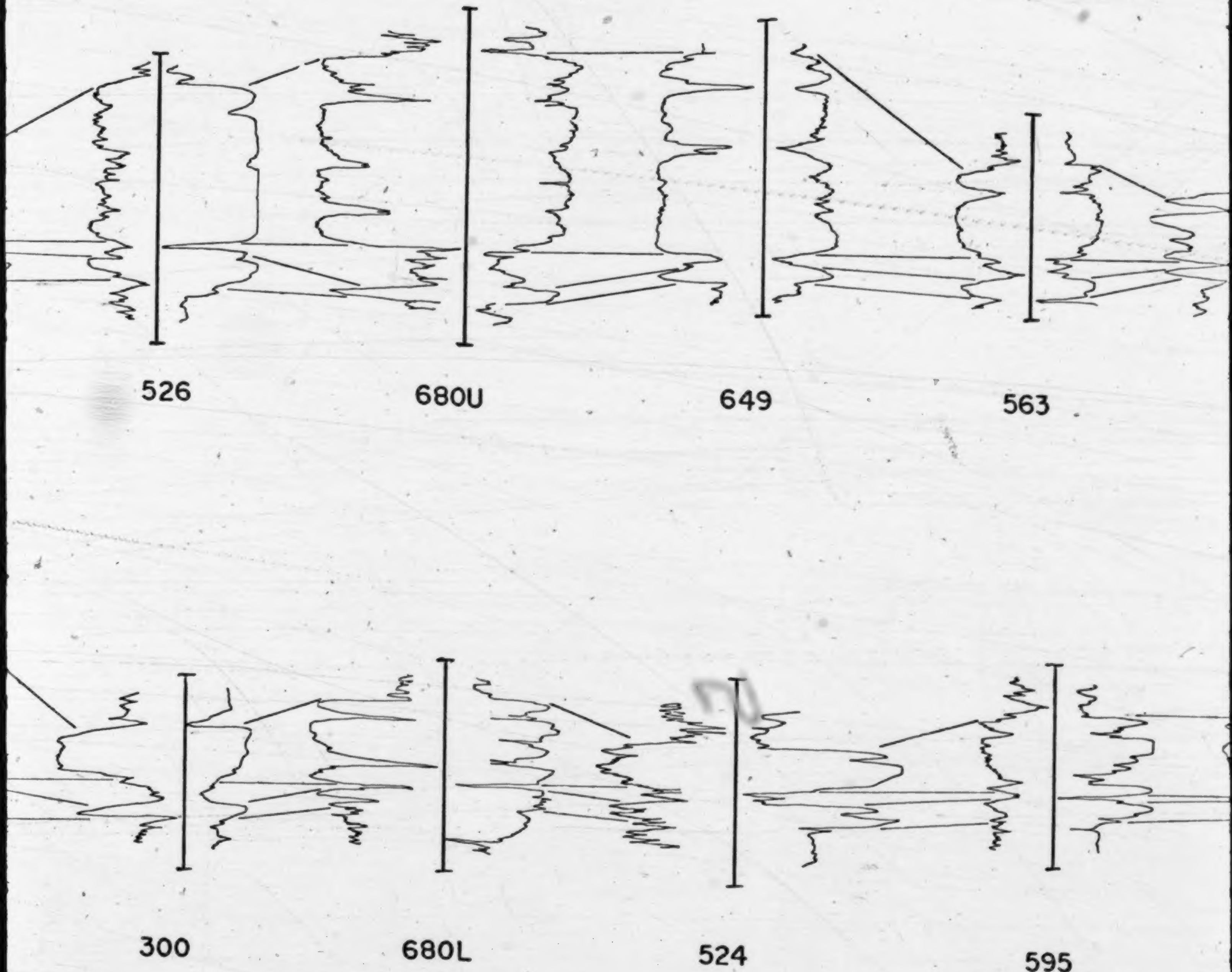
Figure 3. Representative borehole geophysical logs. The natural ga
mark the top and bottom of the seam and of a sandstone parting in the

1 of

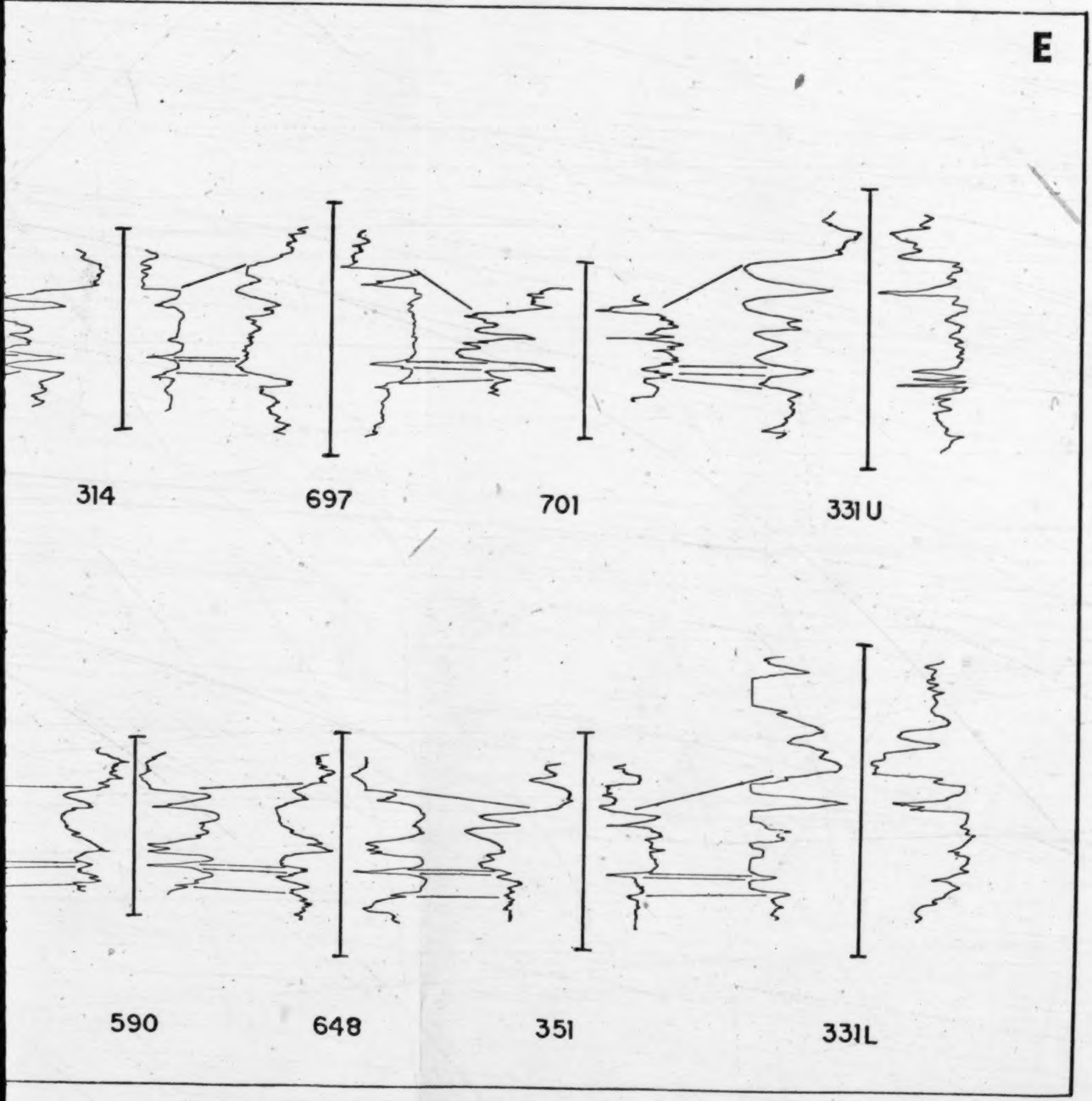


The natural gamma logs are on the left and resistivity on the right. The positions of thes
e parting in the seam. Hole numbers followed by L of U are holes in which the Kennedy seam

2of



positions of these holes are given in Figure 9. The correlation lines
the Kennedy seam was duplicated by a major fault.


E
314
697
701
331U
590
648
351
331L

Mine Data

Subsurface information was available not only from boreholes but also from mine plans of the old underground workings whose distribution is shown in Figure 4. Four kinds of information were found to be particularly useful; (1) Surveyed elevations allowed the (x,y,z) coordinates of about 100 points on the Kennedy seam to be determined and subsequently placed in the computer file MPMW. By comparing the mine entries on the plans with the scars that these entries have left on the ground, these coordinates were adjusted to the map values. (2) Orientations of bedding were noted at about 25 locations. (3) The hanging wall intersections of the Kennedy and Michelin seams with the Drummond Creek thrust were positioned from the eastern limits of mining (Fig. 4). (4) The orientations of the haulageways gave the approximate strike of the Kennedy and Michelin seams.

Data Storage

One of the major objectives of the present study was to use the computer as much as possible to store, retrieve and process structural data. The data involved in these procedures were mainly: (a) coordinates of outcrops, (b) points on the Kennedy seam in boreholes and old mine

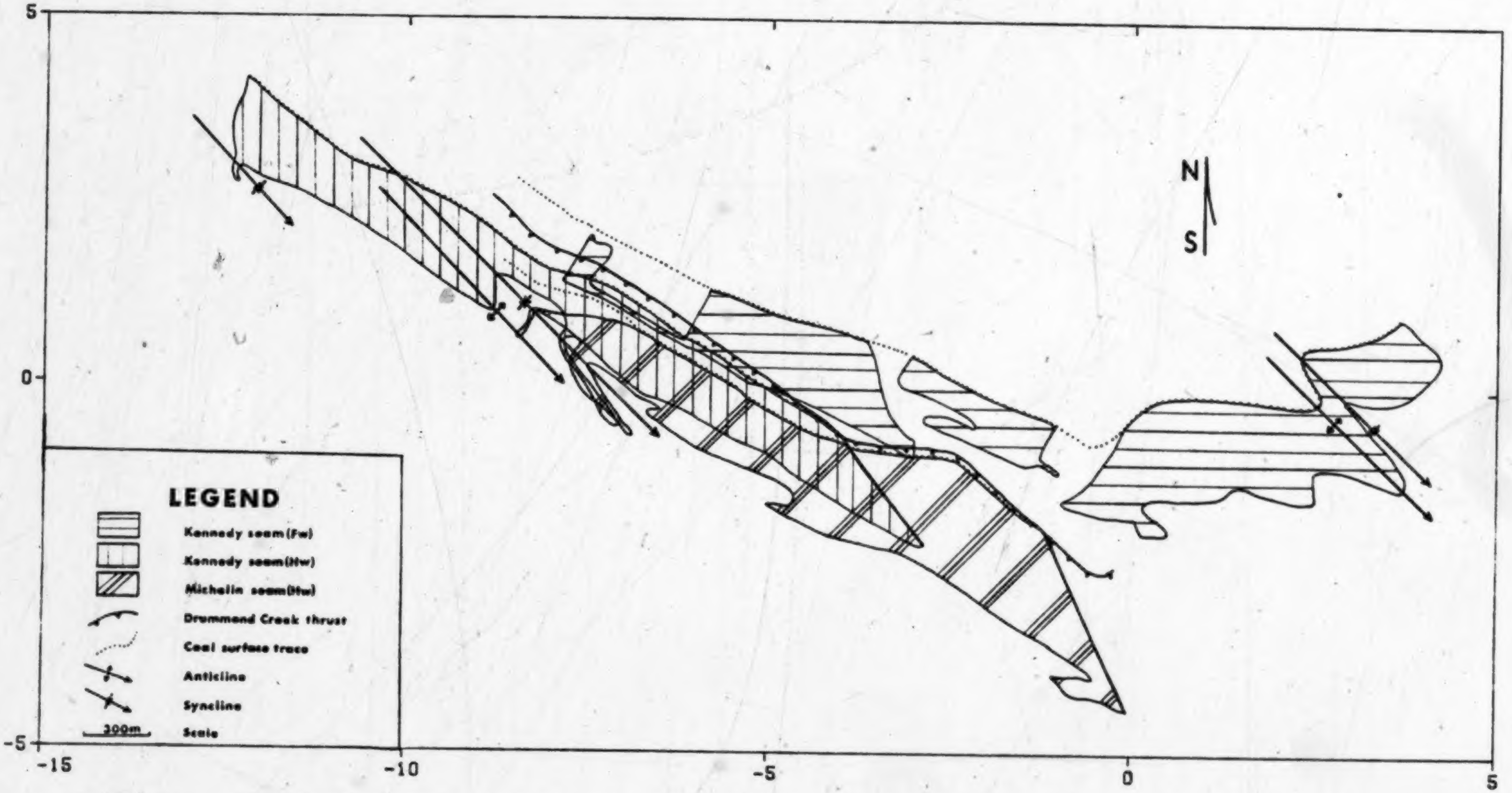

5
0
-5
-15
-10
-5
0
5
N
S
LEGEND
Kennedy seam(Fw)
Kennedy seam(Hw)
Michelin seam(Hw)
Drummond Creek thrust
Coal surface trace
Anticline
Syncline
300m
Scale

Figure 4. Horizontal extent of underground mine workings at Mountain Park.

workings, (c) orientations of bedding, (d) identifications of formations and horizons, (e) data sources and (f) confidence parameters. These data, which come from (1) outcrops, (2) boreholes, (3) subsurface mine workings and (4) an open pit referred to below as the East Pit were placed in five separate files: (a) O/C and MP.AXIS, (b) MPDH, (c) MPMW and (d) MPEP. The files O/C, MP.AXIS and MPEP contain orientation and stratigraphic data obtained from outcrop measurements. Data from the 900 outcrops containing uniformly oriented strata were recorded in O/C whereas data from the 25 outcrops with mesoscopic folds were stored in MP.AXIS. Data collected from 50 stations in the East Pit were stored in MPEP. MPDH contains positional data on the Kennedy seam in 300 boreholes whereas MPMW contains orientation and positional data from the Kennedy seam recorded at 100 locations from plans of the old mine workings. All files were constructed after the end of the field season.

Approximately 900 outcrops were examined during the course of the field season and located on the 1:4 800 and 1:63 360 base maps. Transfer of locations from aerial photographs to the maps were made using relationships to nearby features identifiable on both the map and aerial photographs. Those outcrops that could not be satisfactorily transferred in this manner were accurately positioned using the Bausch and Lomb "Zoom Transfer Scope" at the end of the field season. The error in the position of an outcrop as positioned on the map depended on the accuracy of (1) its position on the aerial photograph, (2) the transfer from photograph to map and (3) the maps themselves. The first source of error is unlikely to be more than 3 m although in a few cases, due to shadows or the featureless nature of the terrain, the difference could be as much as 10 m. The second and third sources of error combined are probably less than 10 m but could be as much as 100 m in the case of the 1:63 360 map. Computerization of the outcrop information required first that the x, y and z coordinates for each station be calculated and recorded. The grid system used was the same as that used during the early mining activity in the area. The origin is at 52.92363° latitude and 117.26973° longitude and the grid, which is measured in feet, is parallel to the Dominion Land Survey. The axes for these coordinates were due east (x), due north (y) and vertically upwards (z). Personnel from the Computing Services Department used a digitizing system described by Perry and Butler (1970) to determine the x and y coordinates directly from the base maps and to place these coordinates along with the corresponding station numbers directly onto magnetic tape. The error associated with this procedure is probably insignificant compared with the errors referred to above. Elevations determined by interpolation between contours were subsequently added to the x and y coordinates on tape. The error in a z coordinate is likely to be one order of magnitude less than the error in the associated x and y coordinates. This procedure was used for all coordinates in files O/C and MP.AXIS. Coordinates used in MPDH and MPEP were calculated from their respective surveys. Borehole collars had been surveyed by professional surveyors whereas the East Pit stations were surveyed and plane tabled by the author. Errors associated with these surveys are probably less than 1 m. Errors associated with positioning borehole intersections due to hole deviation are believed to be minimal due to (1) the shallowness of the boreholes which average 90 m in length, and (2) the large angles, rarely less than 60°, between the strata and the boreholes, most of which were drilled vertically. Coordinates for the MPMW file were obtained by direct measurement from the mine plans. These positions are likely accurate to within 5 m.

Data descriptions, formats and partial listings of O/C, MPDH, MPMW, MPEP and MP.AXIS are located in Appendix 1.

Data files were constructed without any prior knowledge of the format most likely to satisfy the needs of this study. To determine the most convenient format several were used in the hope that one would prove easier to handle. The following conclusions were drawn as a result of this experimentation.

1) Whenever possible numeric rather than alphabetic codes should be used. Although alphabetic characters are

ordered and can be compared, they are more difficult to manipulate.

2) Integers should be used in place of real numbers whenever possible. Integers are easier to manage and provide a more readable printout.

3) Columns of numbers in the file should be separated by spaces, thereby producing a more readable file.

4) A counter specifying the number of orientation measurements at each station should be included. This simplifies programming and cancels the need for an initial counting step in each subsequent program.

5) Although the notation of northings followed by eastings is widely used by surveyors, that of eastings followed by northings is preferred because all computer programs used by the author to process data accept coordinates with this sequence.

6) Dip direction and dip readings should be recorded in integrated rather than segregated format because the processing computer programs accept data with this format.

Data Retrieval

Structural analysis in the study area was carried out in a domain by domain fashion, the data from each domain being processed using several Fortran programs. Before processing could occur, however, the relevant data had to be retrieved from the original file or files, reformatted and placed in a new file. Several Fortran programs were developed to extract the required data from the appropriate file and place them in an Analysis Ready (AR) file whose format is compatible with the processing programs. Outcrop data from the O/C file were obtained by specifying the required outcrop numbers and running the program STATION. Borehole and mine workings data pertaining to the Kennedy seam were retrieved by specifying north-south and east-west limits and running the programs COALADD and COALADD1, respectively. These three types of data were then combined into a single AR-file whose first and last lines were added using the system's EDIT routine. Similar programs written to retrieve data concerning joints, fold axis orientations and surface positions of boreholes were used too rarely to warrant further description here. A detailed description of the contents and format of the AR-file, listings of STATION, COALADD, COALADD1 and a sample retrieval are given in Appendix 2.

Data Processing

Definition of structure and stratigraphy in an area underlain by coal-bearing strata is of the utmost importance in any evaluation of its economic potential. A picture of the structure and stratigraphy of the study area began to be built up while the author was still in the field. After the field season had ended, further analysis of the field, borehole and mine workings data led to the progressive refinement of this picture. Much of this analysis was carried out by processing the data using various numerical computer-based techniques on an Amdahl 470V/6 digital computer. These techniques have several advantages over the graphical and qualitative methods normally used. First, graphical and other errors are eliminated; secondly, the techniques are purely objective; thirdly, the results are reproducible and commonly in a form suitable for statistical analysis, fourthly, the results are more quickly produced and are more accurate. Although Charlesworth _et al_. (1976) and Langenberg _et al_. (1977) have discussed many of these techniques, the author believes that at this point it would be informative to illustrate just how easy they are to implement.

Means and Mesoscopic Fold axes at Outcrops

The repeated measurements of bedding orientation made at outcrops were processed first to determine (1) the mean orientation in the case of outcrops in the O/C file with uniformly dipping strata and (2) the fold axis in the case of outcrops in the MP.AXIS file with mesoscopically folded strata. The mean can be estimated by calculating the sum of unit vectors representing the poles to the repeated measurements. Alternatively it can be found by calculating the eigenvector associated with the maximum eigenvalue of a 3x3 matrix of summed direction cosines of these poles. The fold axis can be found from the eigenvector associated with the minimum eigenvalue of the same matrix (see below).

The Fortran programs MEANS, available in the Department of Geology, and EIGMEAN, listed in Appendix 3(a), can both be used to calculate the mean and fold axis in the cases of uniformly oriented and folded strata, respectively. Whereas EIGMEAN was used to obtain the mean bedding orientations, MEANS calculates the concentration parameter which measures the dispersion of the repeated measurements about the mean (Mardia 1972, p. 251) and was used to test the cylindricity of folding (see p. 25). EIGMEAN also enabled the axes of the mesoscopic folds to be calculated.

Establishment of Potential Domains

Since structural analysis proceeded on a domain by domain basis, the first step was to divide the area into potential domains within which, by inspection, folding appeared to be cylindrical (Fig. 5). The various steps that must be carried out in the analysis of a typical potential domain are listed in Figure 6. Once the limits of a

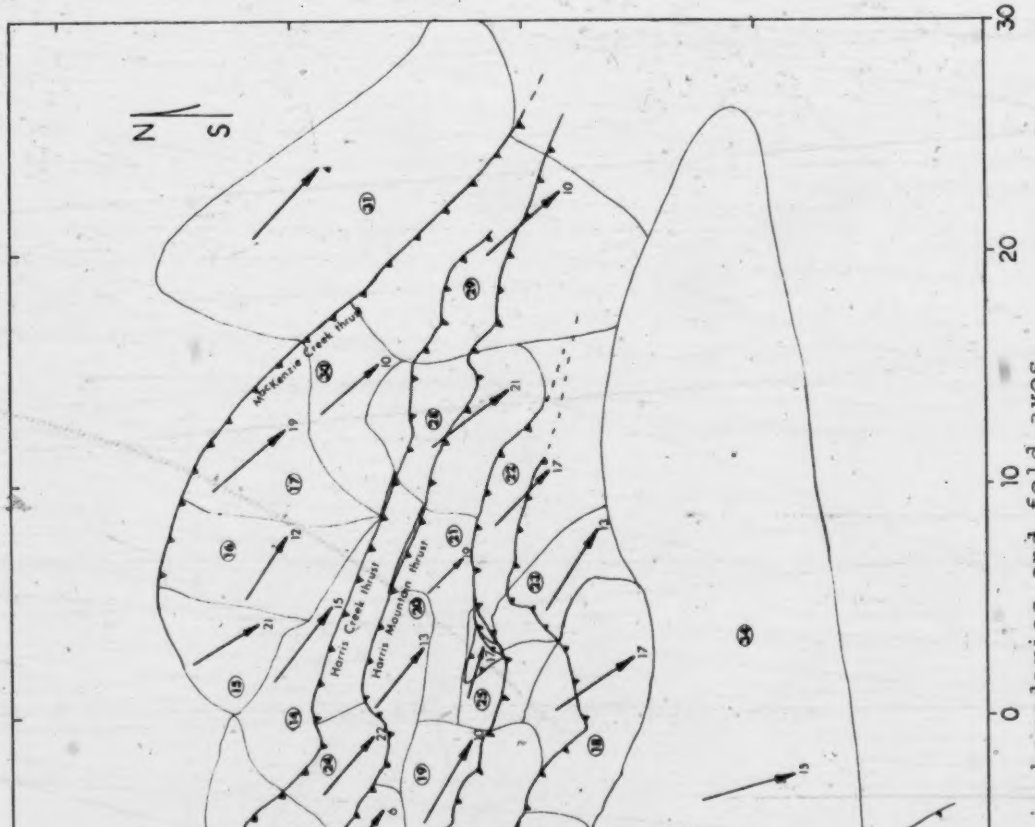

N
S
McKenzie Creek thrust
Harris Creek thrust
Harris Mountain thrust
Prospect Creek thrust
Drummond Creek thrust
McConnell thrust
LEGEND
Domain number
Fold-axis orientation
Domain boundary
Thrust fault
1500m Scale
20
10
0
-10
-20
-30
30

Figure 5. Domain boundaries and fold axes.

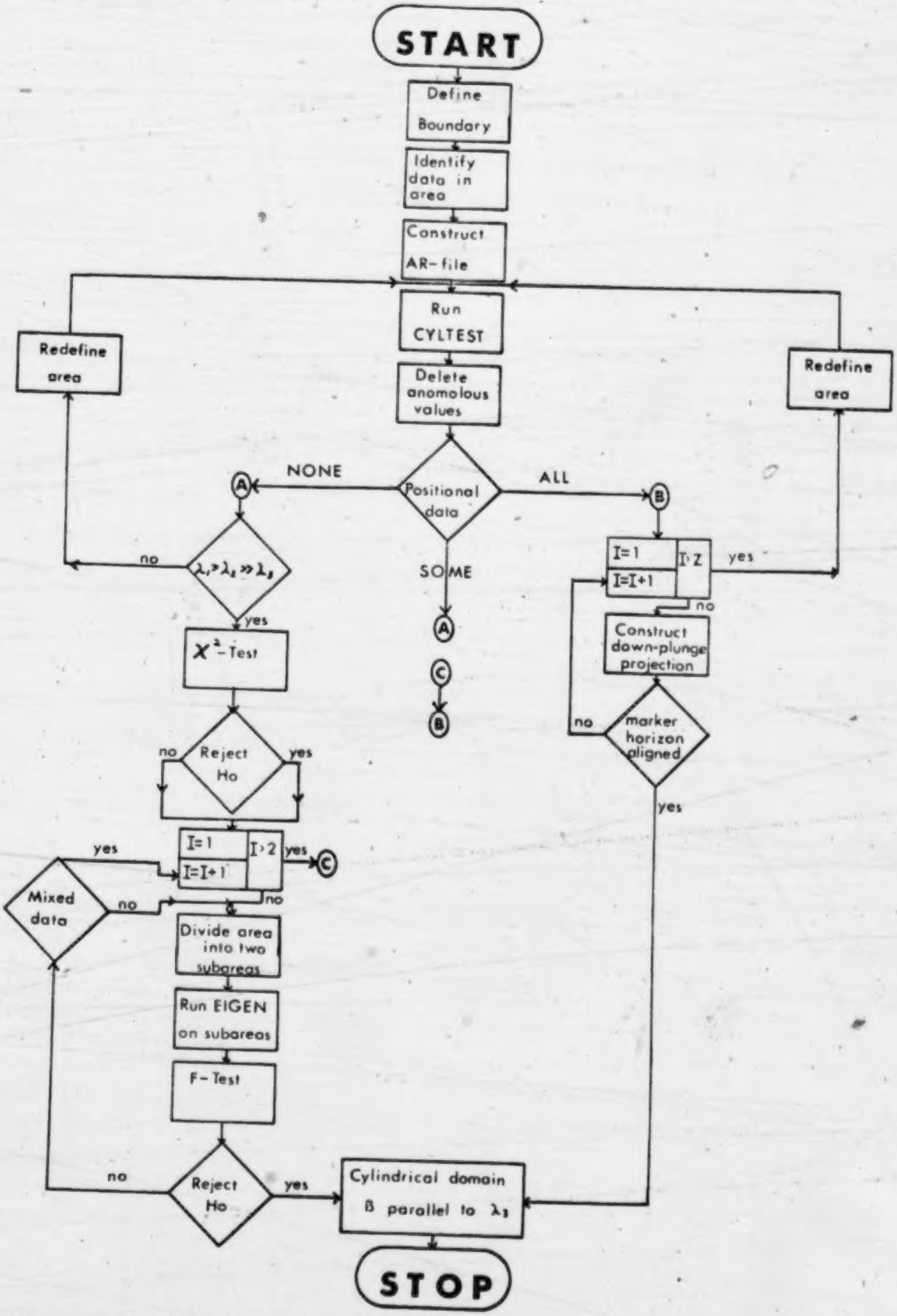

START
Define Boundary
Identify data in area
Construct AR-file
Run CYLTEST
Delete anomolous values
Positional data
NONE
ALL
SOME
A
B
C
Redefine area
Redefine area
no
$\lambda_1 > \lambda_2 \gg \lambda_3$
yes
χ^2-Test
Reject Ho
no
yes
I=1
I=I+1
I>2
yes
no
Mixed data
yes
no
Divide area into two subareas
Run EIGEN on subareas
F-Test
Reject Ho
no
yes
I=1
I=I+1
I>Z
yes
no
Construct down-plunge projection
marker horizon aligned
no
yes
Cylindrical domain
B parallel to λ_3
STOP

Figure 6. Retrieval and cylindricity testing procedure. Z being the number of runs required to define fold axis.

potential domain had been selected the Fortran programs STATION, COALADD and COALADD1 were used to retrieve appropriate outcrop and Kennedy seam subsurface data and place them in an AR-file. Once the AR-file for the potential domain had been constructed the data in it could be subjected to all the analytical procedures described below.

Macroscopic Fold axes

The most important structural element calculated in a potential domain was the fold axis. This orientation was used in the (a) quantitative description of folding, (b) preparation of down-plunge projections and (c) determination of the displacement along faults and the angle between faults and bedding. Thus it was important to estimate the fold axis as precisely as possible. The fold axis was estimated using a method similar to that described above for mesoscopic folds except that the input consisted of the mean orientations of bedding at the various outcrops stored in the file O/C rather than the original field measurements of bedding stored in the file MP.AXIS. Another method for estimating the fold axis that uses down-plunge projections will be discussed on page 30.

Testing Cylindricity

The eigenvector associated with the minimum eigenvalue (minimum eigenvector) of the 3x3 matrix of summed direction cosines gives the fold axis only if folding in the area is cylindrical. Thus the potential domain had to be examined with a view to establishing that it was indeed a domain within which folding could be considered cylindrical. In an ideal cylindrical fold where all the s-poles lie in a plane normal to the fold axis, the minimum eigenvalue, λ_3, is zero. Although some departure from this ideal situation is permitted to allow for measurement errors, bedding-plane roughness and small-scale incongruent folding, clearly should be small: just how small will be discussed below. In addition, a cylindrical fold should have a wide spread of s-poles in the plane normal to the fold axis. A uniform spread yields maximum, λ_1, and intermediate, λ_2, eigenvalues that are almost equal; clearly here the eigenvector associated with λ_3 can, as long as the latter is small enough, be taken to give the fold axis. This is in marked contrast to the situation where the s-surfaces in an area are homoclinal and where λ_1 is large and λ_2 and λ_3 are small and approximately equal to one another: here the fact that λ_3 is small does not mean that the associated eigenvector can be taken to give the fold axis. Obviously, however, there are many situations between the two extremes referred to above where the minimum eigenvector can be assumed to give the fold axis. As long as λ_3 is small and at least one order of magnitude less than λ_2 and as long as λ_1 is within one order of magnitude of λ_2, the minimum eigenvector can reasonably be assumed to give the fold axis.

Charlesworth et al. (1976, pp. 55-56) discussed the measurement of s-pole scatter about the plane normal to the fold axis. Following them, since λ_3 is the sum of $\cos^2\phi_i$ where ϕ_i is the angle between the fold axis and the ith of p s-poles, the variance and standard deviation of $\cos\phi_i$ are given by λ_3/p and the square root of this quantity, respectively. Another measurement of scatter about the plane normal to the fold axis, known as the standard scattering angle, is given by the arcsine of the standard deviation referred to above. One approach put forward by Charlesworth et al. (1976, pp. 55-56) to determine how much scatter is permissible in a cylindrical fold used a chi-square test to compare the variance at the scale of an outcrop, measured by the pooled estimate K of the concentration parameters of the repeated measurements at the outcrops, with the variance in the whole area, measured by λ_3. The null hypothesis of cylindricity was rejected if the product of K and λ_3 was greater than the appropriate value of chi-square. Another approach compared the variance in the area as a whole with that in two halves of the area. Using an F-test, the null hypothesis of cylindricity was rejected if the minimum eigenvalue in the whole area was significantly greater than the sum of the minimum eigenvalues in the two halves.

The author believes that the above two statistical tests of cylindricity should be regarded only as guides rather than final arbiters in deciding whether or not folding in an area is cylindrical. As discussed above, the relative sizes of the three eigenvalues should be taken into consideration. The absolute value of the standard scattering angle in the potential domain should also be considered along with the difference between the orientations of the fold axes in its two halves. Thus the author believes that, standard scattering angles and differences between fold axes of more than 10° and less than 2° can be regarded as sufficient grounds for rejecting and accepting cylindricity, respectively. In spite of the quantitative nature of the above criteria, the final decision concerning the acceptability of an area as a domain within which folding can be considered cylindrical will depend amongst other things on the nature of the study and on the use tc which the fold axis orientation will be put.

The programs CYLTEST and EIGEN already available in the Department of Geclogy were both used to determine the eigenvalues and associated eigenvectors of the 3x3 symmetrical matrix of summed direction cosines. CYLTEST, which accepts an AR-file as input, also calculates the standard deviaticn referred to above and expresses the departure of each bedding-pole from the plane normal to the minimum eigenvector in terms of this standard deviation. This information was extremely useful in detecting apparently erroneous readings and in drawing the boundaries between domains. The program EIGEN accepts an AR-file as input only if it has previously been operated on by the programs STEREO and FINPUT. STEREO, which is described in Appendix 3(b), removes all but the orientation data from the analysis file and FINPUT, already available in the Department of Geology, transforms these data into direction cosines. The STEREO-FINPUT-EIGEN procedure was quicker than CYLTEST in that it was more readily performed on many areas at once. Appendix 3(c) contains a detailed statistical investigation of the cylindricity of the East Pit study area following the proceedures outlined in Figure 6.

Structural Cross sections and Profiles

Cross sections used by the coal industry to calculate reserves are conventionally constructed by taking the coal seam outcrops and borehole intersections immediately adjacent to the line of section and projecting them parallel to the strike. This procedure leaves much to be desired for the following reasons; (1) data some distance away from the line of section are not used, (2) orientational data from outcrops that are stratigraphically adjacent to the coal seam are not used, (3) in the case of a coal seam involved in folds with a moderately to steeply plunging axis, the structural configuration of the seam will be distorted by projecting points parallel to the strike instead of the fold axis.

Cross sections of deformed sedimentary rocks used to illustrate their macroscopic structure are generally constructed to be consistent with outcrop and subsurface data along the line of section and to show the competent stratigraphic units as having maintained their original thicknesses and as having experienced the same shortening parallel to layering. Such "balanced" cross sections do not consider the significant but variable mesoscopic shortening parallel to and thickening normal to layering that affects even the most competent units in the Rocky Mountain Foothills.

Cross sections used to calculate reserves or to illustrate structure may be constructed more accurately and objectively by projecting outcrop and subsurface data over considerable distances parallel to the fold axis onto a plane of section that is either normal or oblique to the fold axis. Such projections can be carried out using the Fortran program SECT5, available in the Department of Geology, which uses an AR-file as input. Where orientation data are available the program calculates the pitch of bedding on the plane of the section. The projection is then constructed by the Calcomp Plotter. The run commands, input, output and resultant plot are given in Appendix 3(d).

Where orientation data were scarce, the method described on page 25 for estimating the fold axis could not be used. As long as sufficient positional data on one stratigraphic horizon are available (for example data provided by boreholes) the above method for constructing down-plunge plots can be used to estimate the fold axis. Various plots are obtained, each associated with its own projection direction. The direction that gives the least scatter of the projected points about a line can be taken to be the fold axis. If a cathode-ray tube terminal is used, a plot can be obtained in a few minutes instead of a few hours as is the case of the Calcomp Plotter, thereby enabling the fold axis for a set of data points to be determined on a trial and error basis within half an hour.

The Fortran program DOMROT, available in the Department of Geology, was used to rotate the orientational and positional data in a domain so that its fold axis became parallel to that in an adjacent domain. Each rotation took place about an origin on the boundary between the two domains involved and about an axis normal to the plane containing the two fold axes. The reason for carrying out such rotations was to enable a single profile to be constructed for areas with varying fold axes. An example of the run commands, input and output for this program is given in Appendix 3(e).

Constructing composite profiles or cross sections of two or three domains is straightforward but where more domains are involved the various rotations should be carried out in a certain order to ensure that discontinuities do not develop between domains. In this study the domains to be rotated tended to occur in elongate strips one or two domains across and up to five domains long. The method followed in carrying out rotations and in constructing cross sections is illustrated in Figure 7.

Map Construction

Maps showing bedding orientations at outcrops were readily constructed by the Calcomp Plotter using subroutines BOUND and MAP listed in Appendix 3(f). A short program incorporating these two subroutines was used to construct maps of varying scales for areas the size of one domain to the size of the study area (see e.g. Fig. 13). Appendix 3(f) contains an outcrop map of the East Pit as well as the program and run commands used in its preparation.

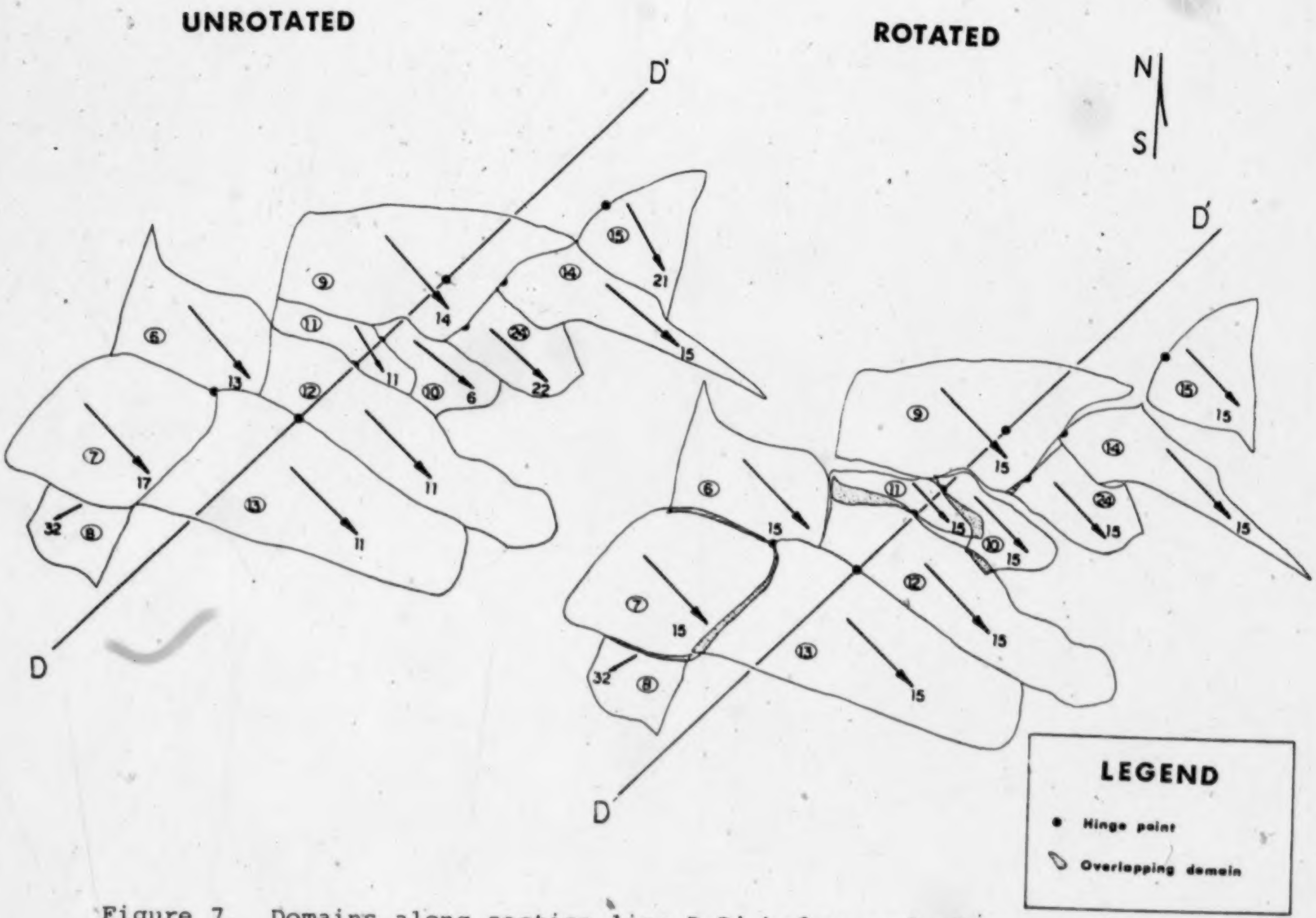

UNROTATED
ROTATED
N
S
D'
D
D'
D
⑥
⑦
⑧
⑨
⑩
⑪
⑫
⑬
⑭
⑮
⑳
13
17
32
14
11
6
22
21
15
11
11
15
15
15
15
15
15
15
15
15
15
32
LEGEND
● Hinge point
Overlapping domain

Figure 7. Domains along section line D-D' before and after rotation.

Orientation Diagrams

Orientation diagrams are very useful in gaining a visual appreciation of orientations in domains and can be prepared with the aid of plots produced by the computer. The plots, which have to be contoured manually, were produced by running the Fortran programs STEREO, PINPUT and PLCT with an AR-file as input. Appendix 3(g) illustrates the construction of an orientation plot for Domain 1.

Thickness Determination

The absence of continuous exposures from most of the study area meant that stratigraphic thicknesses had to be determined indirectly rather than by direct measurement. Each determination involved finding the coordinates of two points, one on the upper, one on the lower bounding surface of the interval in question, and estimating the orientation of the intervening strata. Where the strata are uniformly oriented the thickness can be shown to equal the vector product

$$(x_1 - x_2, y_1 - y_2, z_1 - z_2) \text{ X } l, m, n$$

where $[X_1, Y_1, Z_1]$ and $[X_2, Y_2, Z_2]$ are the coordinates of the two points and [l,m,n] the direction cosines, referred to the same axes, of the normal to bedding. When the strata have been folded on a scale larger than the distance between the two points, i.e. where the orientation varies progressively across the interval, and where folding is parallel in style, a method similar to that developed by Busk (1929, p. 14) was used except that the thicknesses were determined numerically on a plane normal to the fold axis. Thicknesses were calculated using the APL program THICK. A listing of this program together with two sample runs are given in Appendix 3(h).

There were two sources of error in the repetitive thickness calculations: (1) deformation within the measured interval is present in the form of thrusting or small scale folding, instead of being non-existent or such that the orientation of bedding varies progressively from one bounding surface to the other, (2) the dip of the strata within the interval or the coordinates of the two points were incorrectly estimated. Whereas errors of the second type lead either to under- or over-estimations of thicknesses, those of the first type invariably result in the thickness being overestimated. For this reason, after values more than one or two standard deviations from the mean had been excluded, the thickness of an interval was taken to be about midway between the mean and the smallest individual measurement.

STRATIGRAPHY

Strata ranging in age from Devonian to Late Cretaceous crop out in the Mountain Park area. However, because the objective of the study was to examine the structure of the coal-bearing and adjacent strata, only the following map-units were established:

CRETACEOUS	Wapiabi Formation
	Cardium Formation
	Blackstone Formation
	Mountain Park Formation
	Luscar Formation
	Cadomin Formation
	Nikanassin Formation
JURASSIC	Fernie Group
PRE-JURASSIC	Undivided

Pre-Jurassic (undivided)

The pre-Jurassic strata belong to the Devonian Fairholme Group and Palliser Formation, Mississippian Banff Formation and Rundle Group and the Triassic Sulphur Mountain and Whitehorse Formations. These strata consist largely of carbonates and appear to have behaved as a single competent unit with little internal deformation (Plate 1). The Triassic Whitehorse Formation, the uppermost unit of this succession is disconformably overlain by the Fernie Group. A section through the Whitehorse Formation along Drummond Creek is given by Best (1966, p. 63).

Plate 1. Structural terrace in the pre-Jurassic unit, Nikanassin Range east of the junction of Whitehorse Creek and McLeod River.

Fernie Group

The Jurassic Fernie Group consists dominantly of black marine shale with thin bands of sandstone and carbonate. A poorly exposed recessive unit with considerable internal deformation (Plate 2), its thickness was impossible to determine accurately but the 300 m quoted by Frebold (1957, p. 90) for the section along the McLeod River serves as a reasonable maximum value. Whereas the lower boundary is sharp and distinct, the upper contact with the Nikanassin Formation is gradational over approximately 10 m.

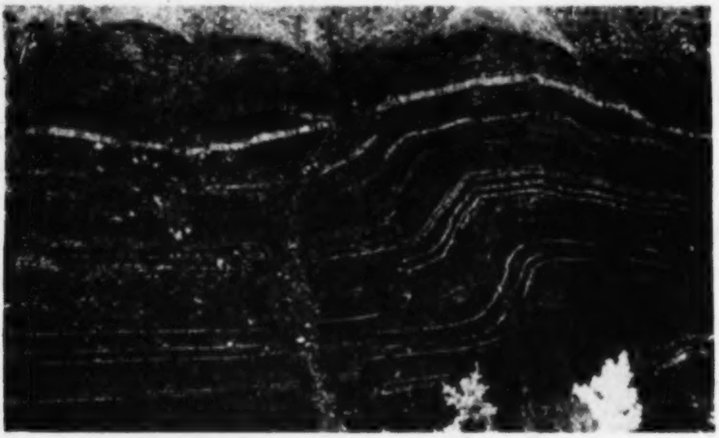


Plate 2. Mesoscopically deformed strata belonging to the Fernie Group along Drummond Creek.

Nikanassin Formation

The Nikanassin Formation of Late Jurassic and Early Cretaceous age consists of about 425 m of medium to thinly bedded sandstone, shale and coaly shale of marine and non-marine origin. Although less recessive and better exposed than the Fernie Group, its precise thickness is difficult to estimate because of internal deformation (Plate 3). MacKay (1930, Fig. 4) suggested a thickness of 480 m whereas Kryczka (1959, p. 10), who measured a continous section 386 m thick along MacKenzie Creek, gave 425 m as the

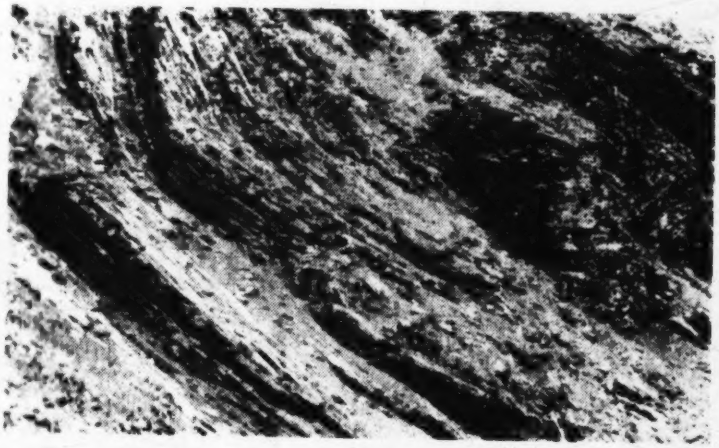


Plate 3. Mesoscopically deformed strata belonging to the Nikanassin Formation along McLeod River.

thickness. Recently, Gibson (1978, p. 380) suggested a thickness of 488 m obtained from measurements along MacKenzie Creek.

Cadomin Formation

The Lower Cretaceous Cadomin Formation unconformably overlies the Nikanassin Formation (Warren and Stelck 1958), although the angularity of the unconformity is probably no more than a few degrees. Only 8 m thick (McLean 1977, p. 798), the formation is largely conglomerate with some thin sandstone lenses. It is extremely resistant and where present usually crops out or forms a ridge. This and its distinctive lithology make it an ideal marker horizon (Plate 4).

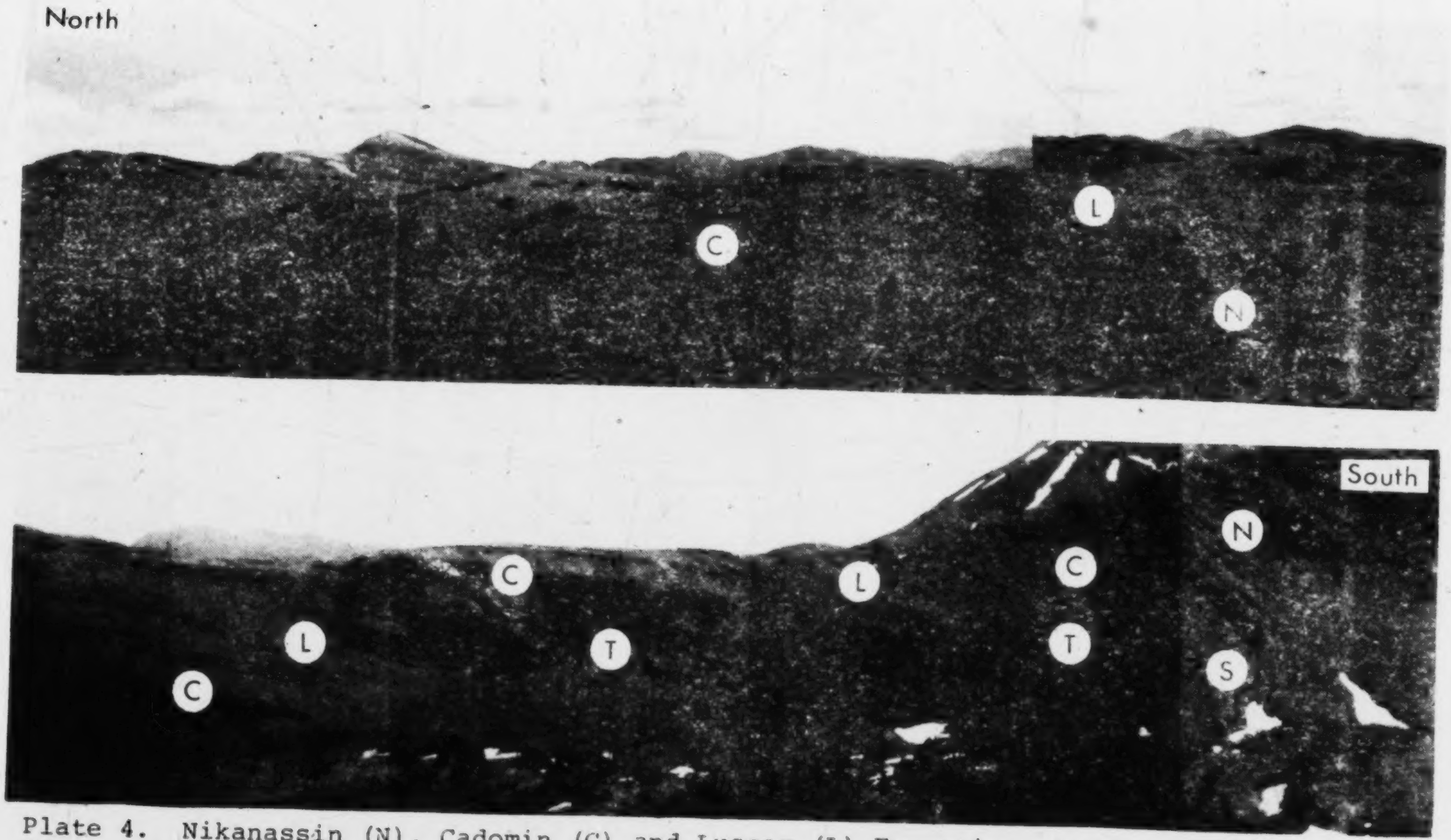

North
C
L
N
South
N
C
L
C
L
C
T
T
S

Plate 4. Nikanassin (N), Cadomin (C) and Luscar (L) Formation along Drummond Creek. Note the Thornton Creek syncline (S) and duplications of the Cadomin Formation by the Drummond Creek thrusts (T).

Luscar Formation

The Lower Cretaceous Luscar Formation bears metallurgical quality coal in the Foothills of west central Alberta. It consists of about 340 m of essentially non-marine sandstone, siltstone, shale and coal (Fig. 8).

Lithologic differences have been noted between the lower and upper portions of the Luscar Formaticn south of the Athabasca River (Douglas 1956, p. 20; Holter and Mellon 1972, p. 129). Similar differences were found in the study area with the lower part containing thinly bedded siliceous sandstones, shales and shaly coals and the upper part thickly bedded kaolinitic and chloritic sandstones and medium to thick coal seams. North of Cadomin the boundary between these two divisions coincides with a band of marine shales equivalent to the Moosebar Formation of northeastern British Columbia. A shale interval containing brackish to marine coquinas that occurs just below the Cheviot coal seam along Cheviot Creek may be an extension of this shale (Plate 5). Due to poor exposure this contact, which is thought to occur about 195 m above the base of the formation, was not detectable elswhere in the study area. The lower 100-125 m of the Luscar Formation are well exposed along Drummond Creek (Plate 4) while typical upper Luscar strata are exposed in and around the West Pit at Mountain Park. The upper boundary of the formation has been placed at the top

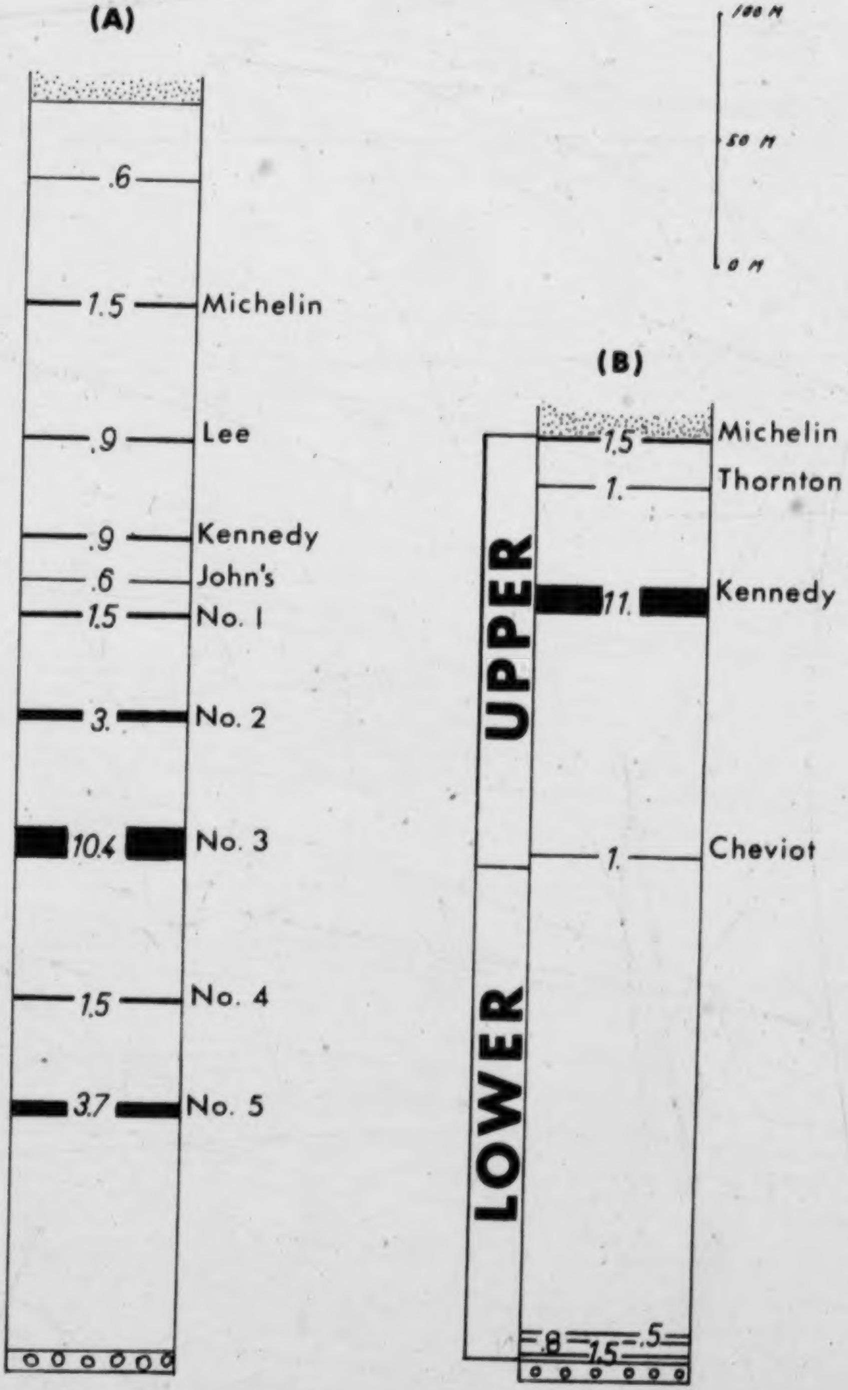

(A)
.6
1.5
Michelin
.9
Lee
.9
Kennedy
.6
John's
1.5
No. 1
3.
No. 2
10.4
No. 3
1.5
No. 4
3.7
No. 5
100 M
50 M
0 M
(B)
1.5
Michelin
1.
Thornton
11.
Kennedy
1.
Cheviot
UPPER
LOWER
.8
1.5
.5

Figure 8. Comparison of Luscar sections (a) MacKay 1930 and (b) the author.

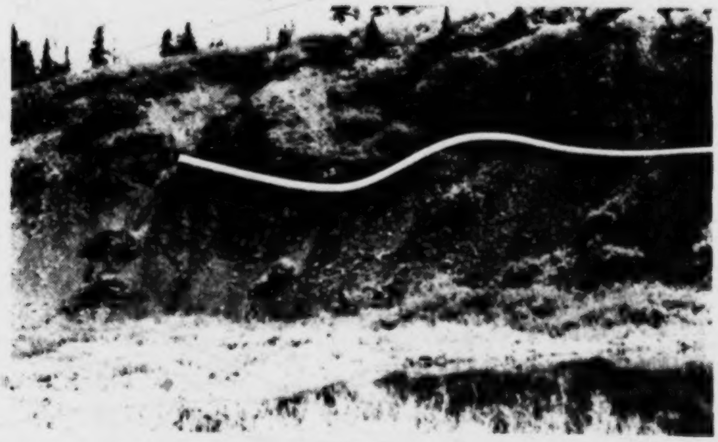


Plate 5. Cheviot seam and underlying shales on Cheviot Creek. The white line marks the base of the coal seam.

of the highest coal seam, the Michelin. Above this seam, which extends throughout the study area, the strata are more resistant to erosion, richer in chlorite and are assigned to the Mountain Park Formation.

The Kennedy seam occurs 270 m above the base of the formation and is the only thick seam in the Mountain Park area. This economically important seam is readily recognizable by its borehole log traces (Fig. 3) and is laterally continous throughout the area (Fig. 9). The seam is divisible into upper and lower benches, 10-11 m and 1 m thick, respectively. The sandstone and shale parting between the two benches is seen to thin abruptly across the trace of the Drummond Creek and Upper Drummond Creek thrust fault from 10 m in the hanging wall to 3 m in the footwall. The majority of coal produced in the Mountain Park area came from this seam. The Kennedy seam is exposed in many old

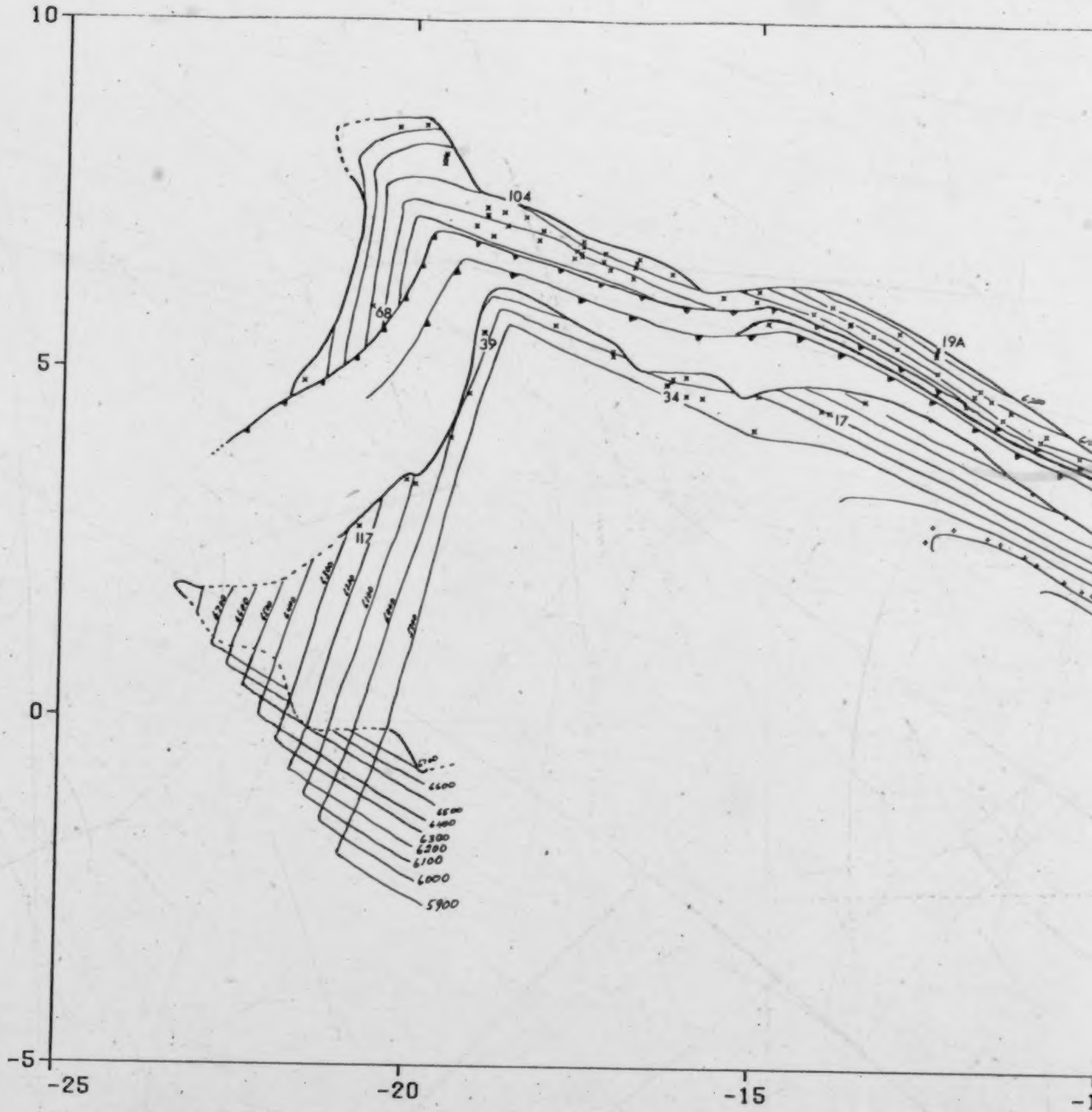
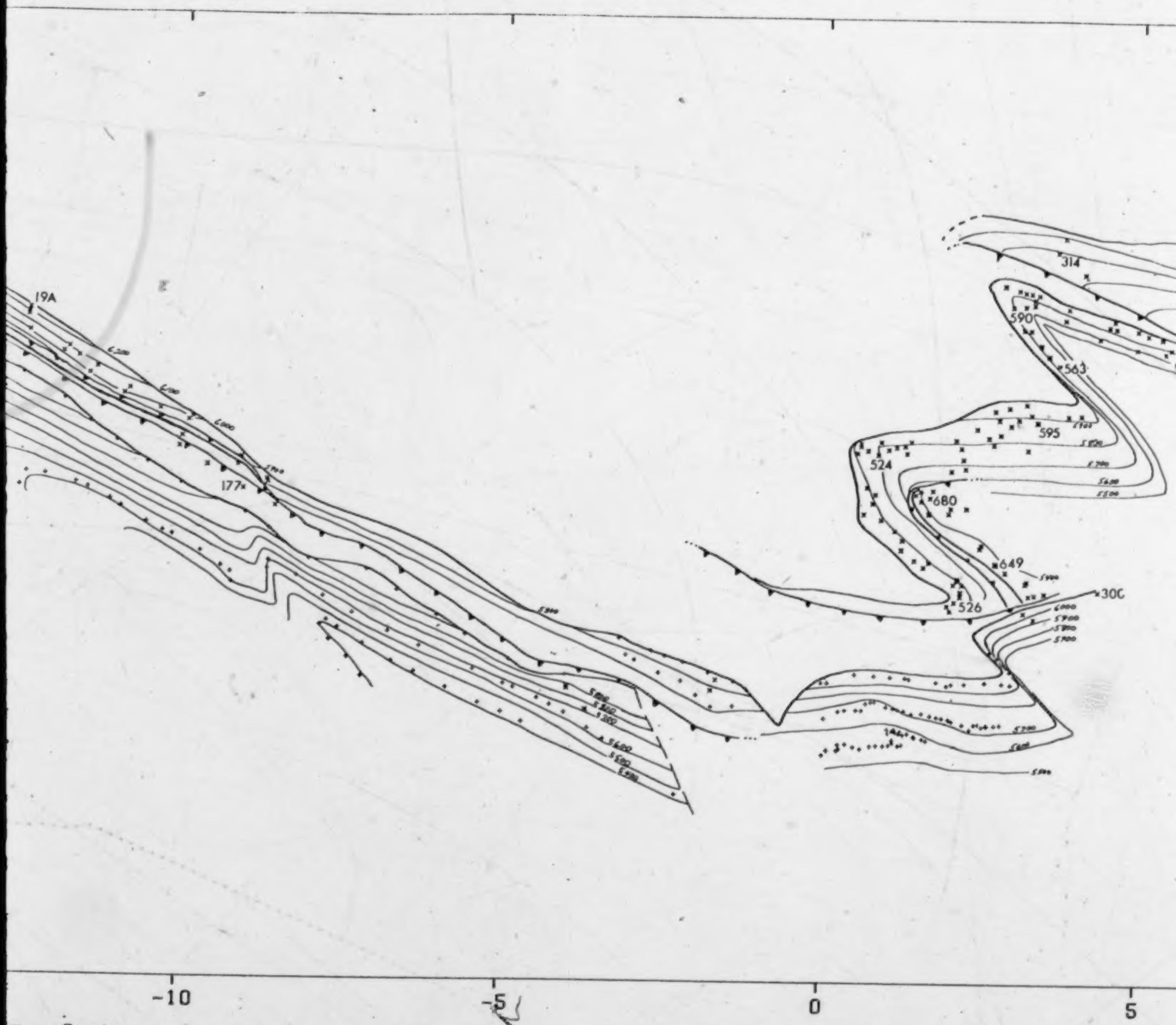
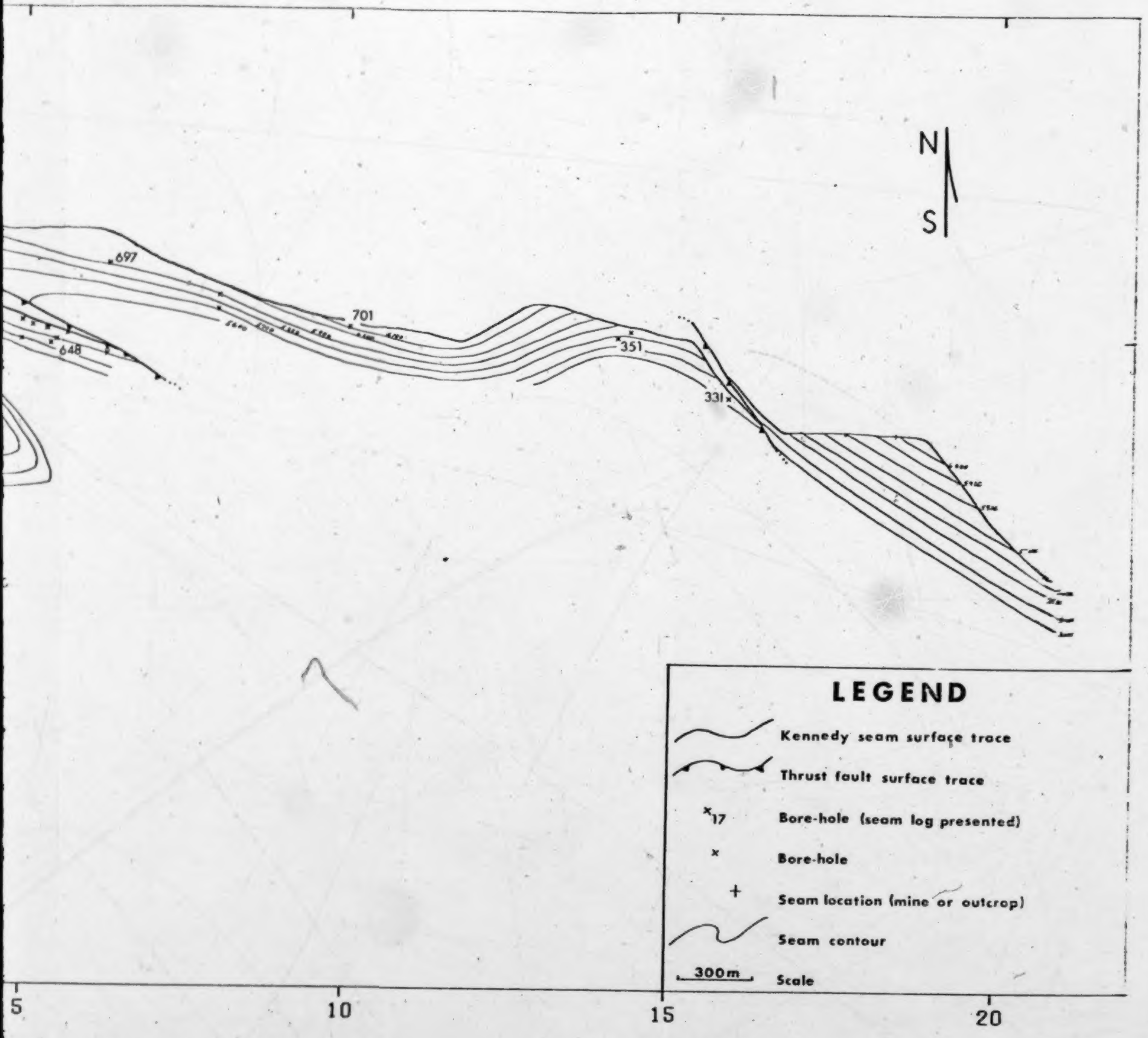

10
5
0
-5
-25
-20
-15
-1
104
68
39
34
17
19A
117
6600
6500
6400
6300
6200
6100
6000
5900

Figure 9. Stucture contour map of the base of the Kennedy seam. Contours

1 of


19A
177
314
590
563
595
524
680
649
526
300
6200
6100
6000
5900
5800
5700
5600
5500
-10
-5
0
5

m. Contours for the hanging wall of the Lower Drummond Creek thrust are not shown.


N
S
697
701
648
351
331
LEGEND
Kennedy seam surface trace
Thrust fault surface trace
×17 Bore-hole (seam log presented)
× Bore-hole
+ Seam location (mine or outcrop)
Seam contour
300m Scale
5
10
15
20

383

excavations in the west and central parts of the area while two natural exposures occur east of MacKenzie Creek (Plates 6 and 7). A stratigraphic section containing the Kennedy and Thornton seam in the West Pit (Plate 8) is given in

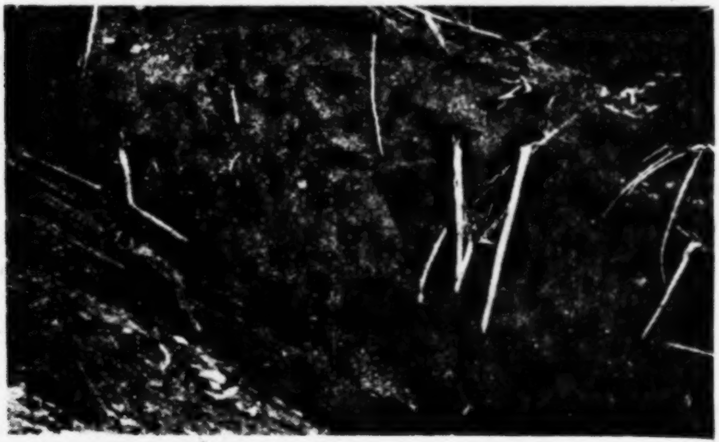


Plate 6. Kennedy seam outcrop 1 km east of MacKenzie Creek. The seam is approximately 9 m thick.

Appendix 5.

The Michelin seam forms the upper boundary of the Luscar Formation. In the central portions of the area where it has been mined a thickness of 1 to 1.5 m is present. The Thornton seam occurs 20 m below the base of the Mountain Park Formation and is approximately 1 m thick. Although never mined, its presence is well defined by borehole evidence and it is laterally quite continuous. The Michelin and Thornton seams are well exposed along the upper tributary to MacKenzie Creek at an outcrop whose coordinates

Plate 7. Outcrop of the Kennedy seam with well developed cleat 2 km east of MacKenzie Creek. Clipboard is 30 cm long.

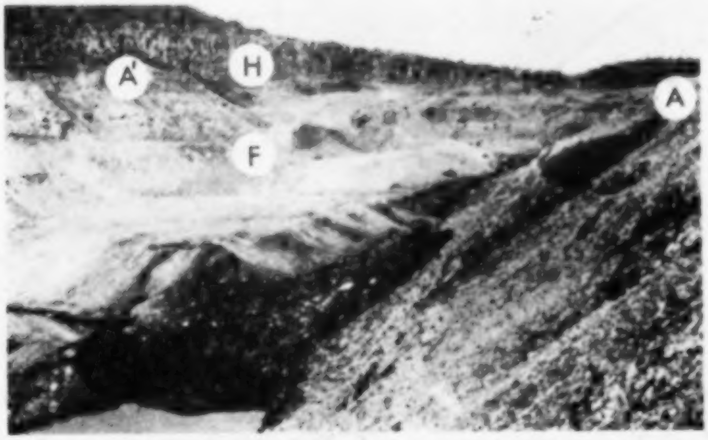


Plate 8. The West Pit viewed from the east. The Kennedy seam and lower bench are in foreground. The stratigraphic section given in Appendix 5 was measured fom A to A', F marks Drummond thrust and H marks the Kennedy seam in the hanging wall of the Drummond Creek thrust.

are 17 000 east and 3 000 north. The Cheviot seam, approximately 1 m thick, occurs about 195 m above the Cadomin Formation and is not believed ever to have been mined. It is seen only in a few boreholes in the eastern portion of the area and at one outcrop along Cheviot Creek (Plate 5). Several other thin shaly coal seams occur within 20 m of the base of the Luscar Formation, and other thin seams occur throughout the formation but due to lack of data their precise stratigraphic position and lateral extent are unknown.

Lack of good exposure meant that the thicknesses of various intervals within the Luscar Formation and of the formation itself could not be measured directly. Instead thicknesses were estimated using repetitive measurements determined by applying the numerical techniques described on page 34 in areas where the structure is approximately homoclinal. The various thickness determinations are as follows.

1) Thickness of the interval between the Kennedy and Thornton seams was obtained from data in eighteen boreholes situated throughout the map area. These yielded a mean of 52 m and a standard deviaticn of 6.6 m. After removing four anomalous values a mean of 52.7 m and a standard deviation of 3.3 m were obtained. The smallest of the remaining 14 values was 48.7 m so the thickness of this interval has been taken to be 51 m.

2) Thickness of the interval between the Michelin and Thornton seams, determined from eight borehole

measurements east of the McLeod River, gave a mean thickness and standard deviation of 25.3 m and 13.2 m, respectively. The removal of two anomalous values changed the mean to 20 m and the standard deviation to 2 m. Of the six remaining values 18 m was the minimum so an interval thickness has been set at 19 m.

3) Thickness of the interval between the Kennedy seam and the Mountain Park Formation, which equals the sum of the above two thicknesses, was also obtained by repetitive calculations based on the old mine plans. Four determinations yielded a mean and standard deviation of 75 m and 9.5 m, respectively. The minimum value was 66 m, which suggests a thickness of about 71 m for this interval. This value is in good agreement with the sum of thickness determinations 1 and 2 (70 m).

4) The interval between the Cadomin Formation and the Kennedy seam has the least intermediate control and being the thickest is the most important in establishing the total thickness of the formation. Repetitive calculations from map positions between McLeod River and Prospect Creek yield a minimum thickness of 260 m with a mean and standard deviation of 278 m and 19 m, respectively. A value of 269 m has been accepted as being the best estimate of the true thickness.

5) Only one borehole intersection of the Cheviot seam could be stratigraphically positioned. The outcrop along Cheviot Creek was of no value in locating the seam

stratigraphically due to structural complexities. In the borehole, located east of McLeod River, the seam occurs 73 m below the Kennedy seam.

The total thickness of the Luscar Formation (340 m) and the distribution of coal seams within it described above differ considerably from those given by MacKay (1930, Fig. 5) who derived his information from the active mine workings. MacKay proposed that the formation is 485 m thick and contains 11 seams (Fig. 8). The author is convinced that the discrepancy between his and MacKay's figures is caused by (1) MacKay's failure to observe several large thrusts in the mine workings and (2) the author's positioning of the boundary with the Mountain Park Formation at the top of the Thornton seam which MacKay considered to be well within the Luscar Formation. By comparing borehole logs, it can be shown that several of MacKay's seams are one and the same. The Kennedy and #3 seams of MacKay both appear to be equivalent to the author's Kennedy seam in the hanging wall of the Upper Drummond Creek thrust and footwall of the Drummond Creek thrust, and very likely his #5 seam is the Kennedy seam in the McLeod River thrust sheet.

Through the use of borehole logs, the Kennedy seam was found to be laterally continuous throughout the Mountain Park area. The presence of a thick and laterally extensive coal seam in the study area and similar occurrences nearby at Cadomin and Luscar initiated an attempt to correlate the seams and sections in these two areas with those at Mountain Park. Through a literature search and consultation with several coal companies surprising similarities in the Luscar and equivalent coal-bearing strata of the Foothills from the Saskatchewan River in the south to Mount Belcourt in the north were found (Figs. 10 and 11). Correlations were based on (1) height above the Cadomin Formation of the major seam in each section, (2) stratigraphic position and thickness of other seams within the section, (3) stratigraphic position of the Moosebar Formation and the equivalent marine shales within the Luscar Formation, (4) similarities in borehole log traces of seams and surrounding strata (Fig. 12).

Several published sections through the Luscar Formation are not readily correlatable with those shown in Figure 10. The author feels that this may result from the failure on the part of the compilers of these sections to recognize structural complexities such as those seen at Mountain Park. Also local depositional peculiarities may complicate correlation.

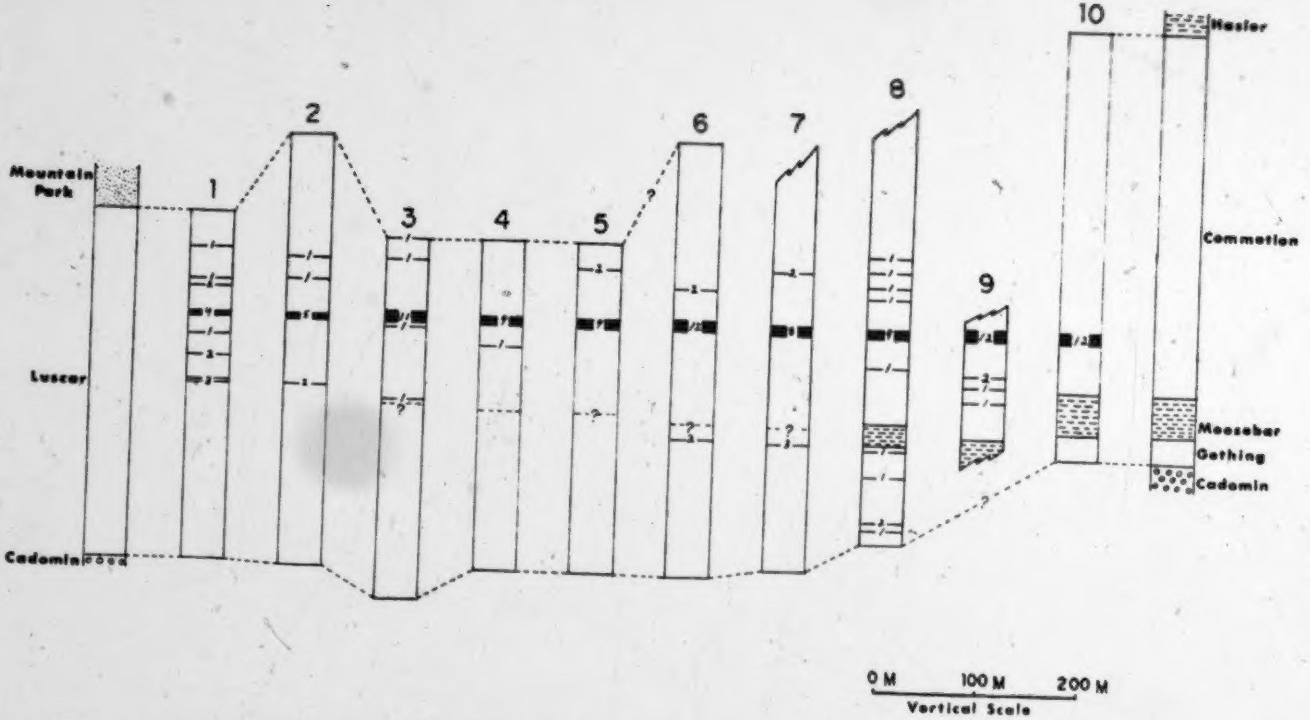

Mountain Park
Luscar
Cadomin
1
2
3
4
5
6
7
8
9
10
Nesler
Commotion
Moosebar
Gething
Cadomin
0 M
100 M
200 M
Vertical Scale

Figure 10. A comparison of Luscar sections from Nordegg, Alberta to Mount Belcourt, British Columbia. The locations of these sections are shown in Figure 11.

(1) Nordegg; Consolidation Coal 1976
(3) Mountain Park; author
(5) Luscar; Luscar Ltd. 1977
(7) Muskeg River; MacKay 1930
(9) Torrens River; Consolidation Coal 1977
(2) Muskiki Lake; Luscar Ltd. 1977
(4) Cadomin; Mellon 1967
(6) Thoreau Creek; MacKay 1930
(8) Smoky River; Wrightson 1978
(10) Mount Belcourt; Stott 1968

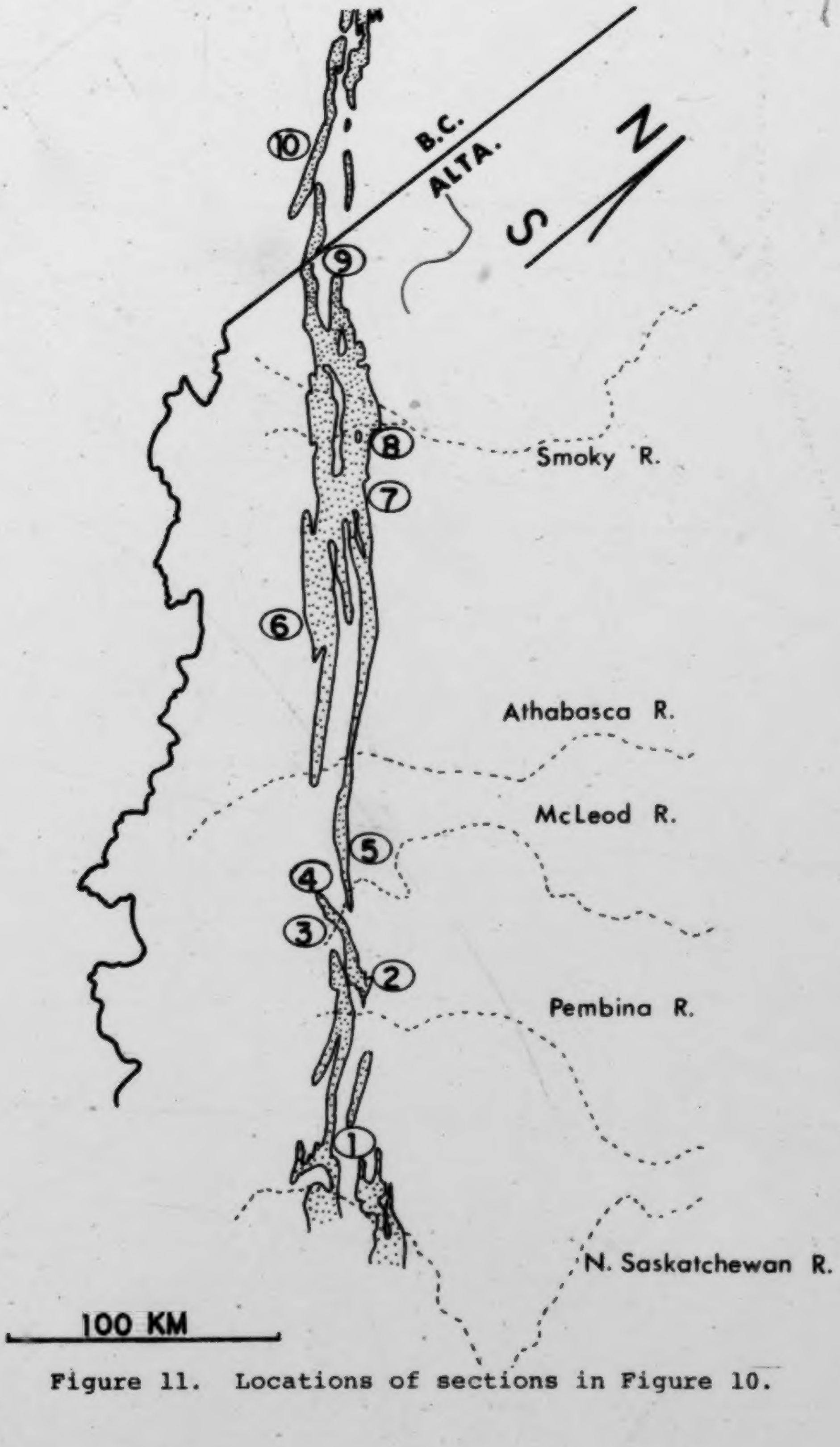

B.C.
ALTA.
N
S
10
9
8
7
6
5
4
3
2
1
Smoky R.
Athabasca R.
McLeod R.
Pembina R.
N. Saskatchewan R.
100 KM

Figure 11. Locations of sections in Figure 10.

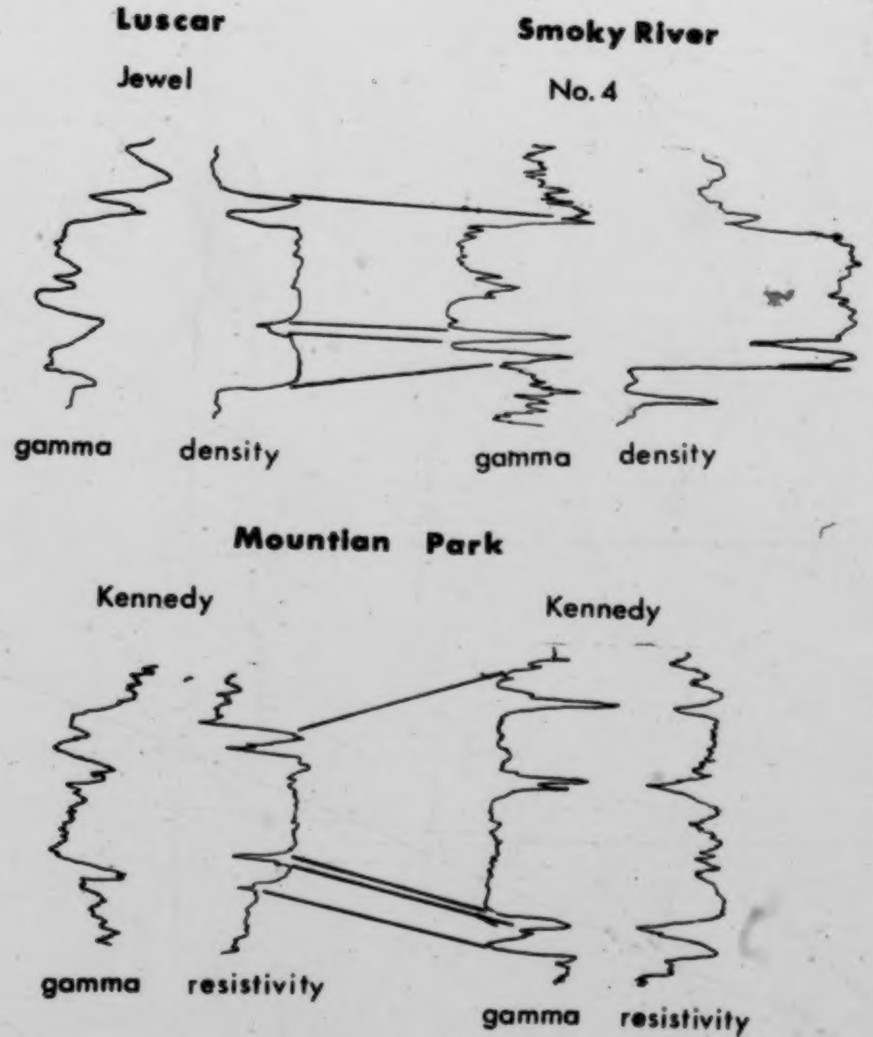


Figure 12. Comparison of borehole geophysical logs from Mountain Park, Luscar and Smoky River.

Mountain Park Formation

The Lower Cretaceous Mountain Park Formation consists of about 200 m of non-marine olive-green sandstones and shales with local black chert pebble conglomerate lenses present near the base. Plant remains and well preserved fossil wood are common. The resistant nature of the thick sandstones of this formation produces prominent ridges throughout the area (Plate 9). The placing of the lower boundary of the formation at the top of the Michelin seam, located well within the Luscar of MacKay, has increased the thickness of the formation by at least 76 m from the 120 m suggested by MacKay (1930, Fig. 4) and provided a more

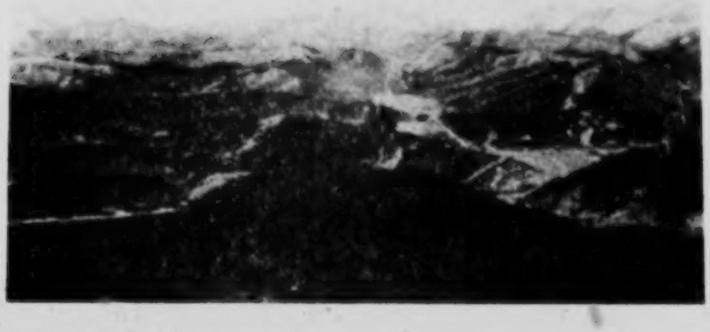


Plate 9. Looking west across Mountain Park from the Cardium ridge. The West Pit is in the center with the Cadomin and Mountain Park ridges to the north and south, respectively. recessive Blackstone strata underlie the ground south of the Mountain Park Formation.

mappable boundary. No complete well-exposed section is present in the area but a composite type section could be constructed from outcrops along MacKenzie Creek. The Mountain Park Formation is disconformably overlain by the Blackstone Formation (Stott 1963, p. 25).

Blackstone Formation

The Upper Cretaceous marine Blackstone Formation is composed of recessive dark-grey to black shales, siltstones and rare fine grained sandstones (see e.g. Stott 1966). Due to poor exposure no reliable thickness determinations were made and Stott's (1963, Fig. 15a) thickness of 430 m has been accepted. The formation is conformably overlain by the Cardium Formation.

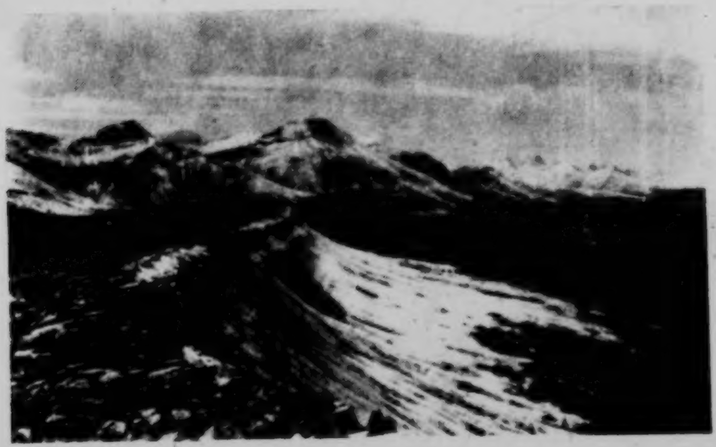


Plate 10. Looking west along the Cardium Formation. Note Cardium strata in the core of Thornton Creek syncline at the base of Cheviot Mountain in the center of photograph.

Cardium Formation

The Upper Cretaceous Cardium Formation, referred to as the Bighorn Formation by MacKay (1929, p. 474) is a dominantly marine unit of thickly interbedded sandstones and shales. The formation is 75 m thick (Stott 1963, Fig. 16a), extremely resistant and forms a prominent ridge along the southern boundary of the study area (Plate 10).

Wapiabi Formation

Black marine shales of the Upper Cretaceous Wapiabi Formation are present only in the southern portion of the study area.

STRUCTURE

Strata near Mountain Park are disrupted by several thrust faults that generally cut up section to the northeast at low angles. Although both the thrusts and the faulted strata have an overall dip to the southwest, folds are common. Some folds are restricted to individual thrust sheets whereas others are more extensive (Fig. 13, in pocket). The area has been divided for descriptive purposes into five structural units separated by four major thrust faults (Fig. 5).

The area is also divisible into 32 domains within which folding can be considered cylindrical (Fig. 5). Whereas some domains straddle the boundary between two structural units, most are confined to a single unit. Each domain satisfies the test of cylindricity described on page 25. A structural profile for each domain was constructed with the aid of a computer constructed plot showing the projections of data stations parallel to the fold axis onto the plane of the profile and where possible the traces of bedding (Appendix 4). By rotating adjacent domains so that their fold axes coincide, five composite vertical cross sections were constructed and combined to produce one stacked cross section (Fig. 14).

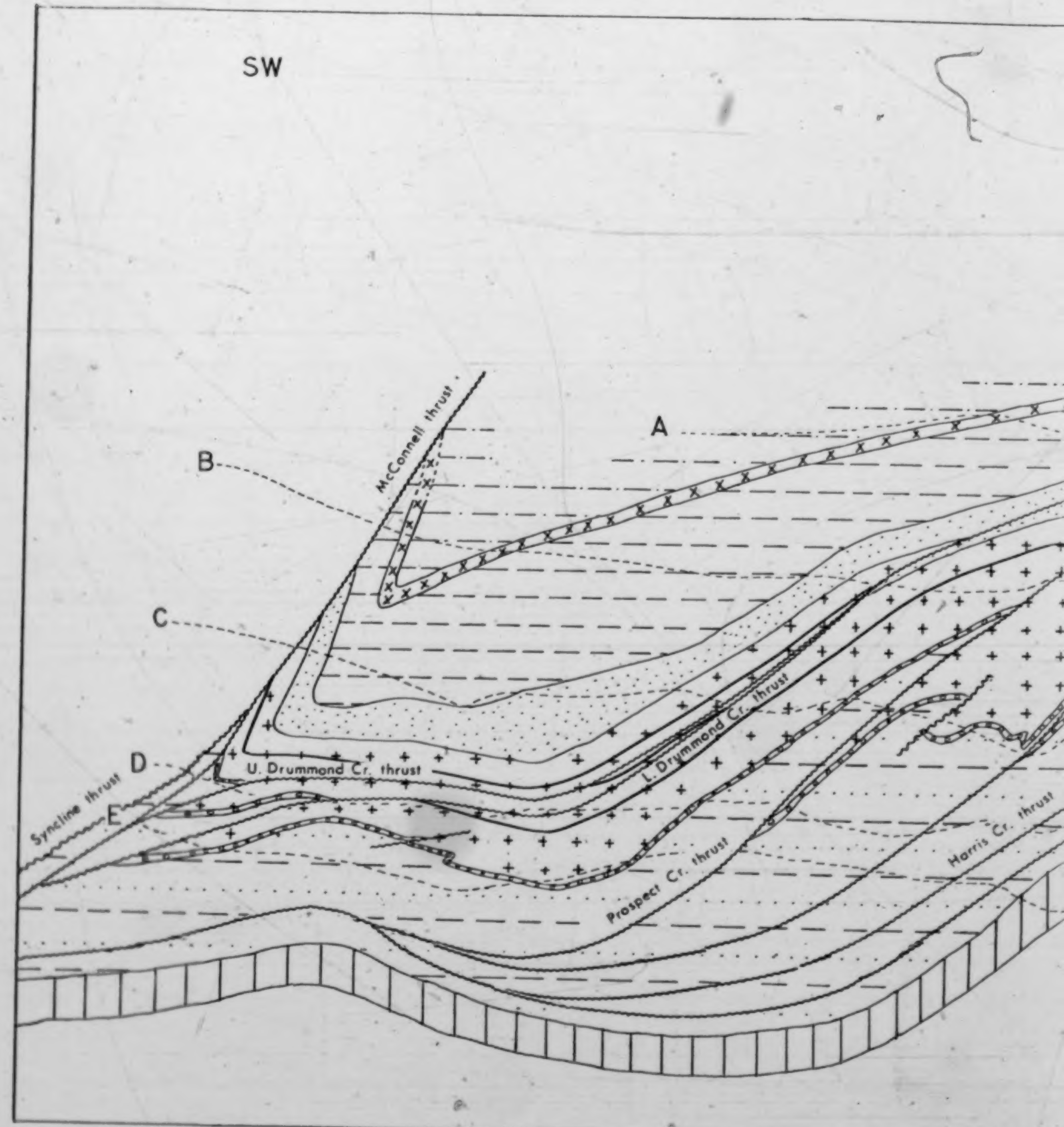
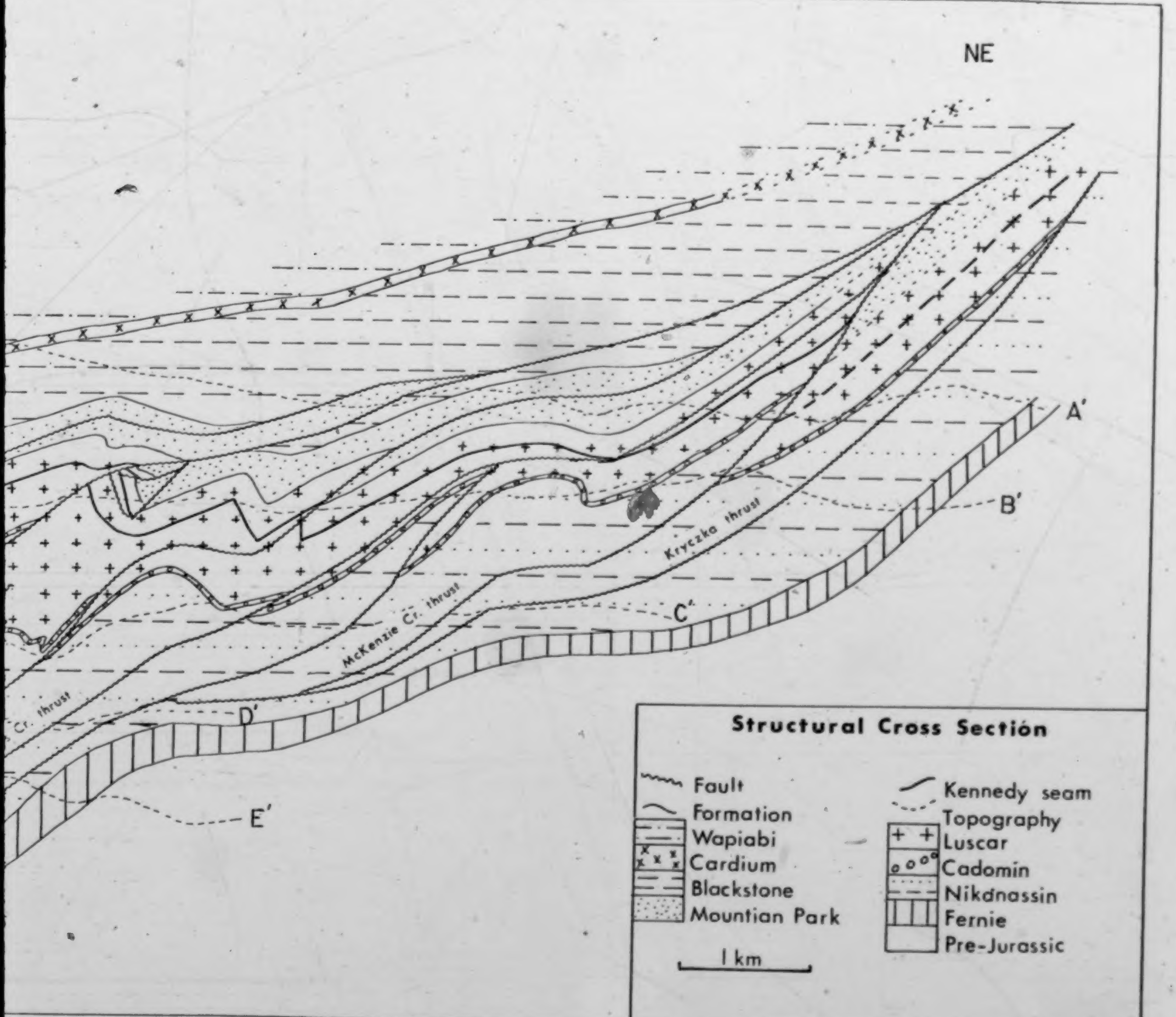

SW
A
B
C
D
E
McConnell thrust
U. Drummond Cr. thrust
L. Drummond Cr. thrust
Syncline thrust
Prospect Cr. thrust
Harris Cr. thrust

Figure 14. Stacked vertical cross section for the entire map area, proj

1 of


NE
A'
B'
C'
D'
E'
Kryczka thrust
McKenzie Cr. thrust
Cr. thrust
Structural Cross Section
Fault
Formation
Wapiabi
Cardium
Blackstone
Mountian Park
Kennedy seam
Topography
Luscar
Cadomin
Nikanassin
Fernie
Pre-Jurassic
1 km

, projected onto the B-B' section.

Drummond Creek thrust sheet

The Drummond Creek thrust sheet in the southern part of the map area is bounded above and below by the McConnell and Drummond Creek thrusts. Since these faults generally strike southeasterly and easterly, respectively, the width of the thrust sheet increases eastwards from 0.6 km to 9 km. Exposures belong mainly to the Nikanassin, Cadomin and Luscar Formations in the west and to the Mountain Park and Blackstone Formations in the east.

Drummond Creek thrust

Two thrusts, referred to here as the Lower Drummond Creek and Upper Drummond Creek thrusts are well exposed just east of Drummond Creek in the southeast corner of the map area where Nikanassin and Cadomin strata are thrust over the Luscar in both instances. A short distance to the east the Lower Drummond Creek thrust truncates the Kennedy seam in the footwall. Between Prospect and Thornton Creeks both faults are within the Luscar Formation and are responsible for the triplication of the Kennedy seam indicated by borehole data. A short distance east of the West Pit these two thrust faults merge to form the Drummond Creek thrust. Between Thornton Creek and the McLeod River, as seen on the plans of the old mine workings, the fault truncates the

Kennedy and Michelin seams in the hanging wall before apparently becoming parallel to bedding near the top of the Luscar Formation (Fig. 4); in the same distance the fault cuts up through the Mountain Park Formation in the footwall before apparently becoming parallel to bedding near the base of the Blackstone Formation. Between Harris Mountain and MacKenzie Creek the fault cuts up through the Mountain Park Formation in the hanging wall and enters the Blackstone Formation in which it becomes lost to view. Northwest of Drummond Creek the thrusts enters the Nikanassin Formation and appear to merge with the McConnell thrust.

As seen from their traces on the map and cross section (Figs. 13 and 14), the Drummond Creek thrust and its two branches are approximately parallel to bedding and have obviously been folded. Assuming that (1) the folds in the faults and in bedding have the same fold axis, (2) the thickness of the interval between the Cadomin Formation and the Kennedy seam is 270 m and (3) the points where the faults truncate the Cadomin Formation and the Kennedy seam are as shown on Figure 13, then the average angle that the Lower Drummond Creek fault makes with bedding in the hanging wall between Prospect and Thornton Creeks is 5°. The corresponding angles for the hanging wall and footwall of the Upper Drummond Creek thrust are about 3° and 5°, respectively. Both faults cut up section to the northeast. Support for the first of the above three assumptions, the only one seriously in doubt, comes from the fact that the thrust to bedding intersection in the hanging wall of the Drummond Creek thrust is approximately parallel to the fold axis in the area of the former mine workings. The orientation of the intersection is readily determined from the mine plans by the position where the Kennedy and Michelin seams are cut off to the east by the fault (Fig. 4). There is no way of knowing whether the bedding to thrust angle remains constant at 3 to 5° or whether the thrusts are stepped.

Using the points of truncation of the Kennedy seam and the base and top of the Mountain Park Formation, the average angles between the Drummond Creek fault and bedding in the hanging wall west and east of the McLeod River are 7° and 5°, respectively. The average angle between the fault and bedding in the Luscar and Mountain Park Formations in the hanging wall is 6°. Using the points of truncation of the Kennedy seam and the base of the Mountain Park Formation in the footwall, the average angle between the fault and bedding in the footwall east of Prospect Creek is 1°.

Fold axis orientations in general do not differ significantly across the trace of the Drummond Creek thrust which suggests not only that the fault is approximately parallel to bedding but that there is no appreciable rotational component to the displacement along it. Assuming the direction of displacement along the fault to be normal to the fold axis the relative positions of the points in the hanging wall and footwall of the Lower and Upper Drummond Creek thrusts at which the Kennedy seam is truncated gave values for the displacements of 2.75 and 2.06 km respectively. That the displacement along these faults is considerable is substantiated by the abrupt thickening of the parting between the two benches of the Kennedy seam across the traces.

The thrust sheet

Strata within the Drummond Creek thrust sheet have been faulted and folded, in places independently of and in places along with the Drummond Creek thrust and its footwall. Among the folds present in both hanging wall and footwall are the Drummond Creek anticline and syncline between Drummond and Prospect Creeks and the East Pit anticline and syncline between the McLeod River and MacKenzie Creek. These structures are described on page 80. Among the structures confined to the thrust sheet itself are the Thornton Creek syncline, several minor folds on the northeast limb of this syncline and the Syncline thrust.

The Syncline thrust marks the northeastern boundary of a fault zone whose southwestern boundary is the McConnell thrust. Nikanasssin strata form the hanging wall for the entire exposure length whereas Cadomin and Luscar strata are found in the footwall. The fault has Luscar and Cadomin strata in the footwall along Drummond Creek (Plate 4), Luscar to the south of the Syncline Pit (Plate 11) and Cadomin again at the headwaters of East Prospect Creek (Plate 12). The fault and the overturned Nikanassin and Fernie strata within the fault zone are approximately parallel at 219/45.

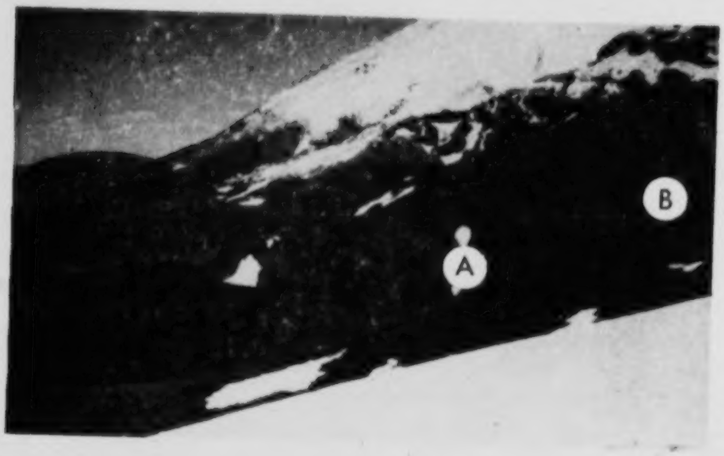


Plate 11. Looking east along Thornton Creek syncline. Note Kennedy seam excavation, Syncline thrust (A) and McConnell thrust (B).

The Thornton Creek syncline is the largest single structure in this unit, containing strata from the Fernie Group to the Wapiabi Formation. An overturned plunging fold, its fold axis and axial plane have orientations of 150/17

Plate 12. Old adit in the overturned Kennedy seam, southwest limb of Thornton Creek syncline. The Cadomin Formation is at A.

and 210/34, respectively. Overturned strata in the narrow southwestern limb of the fold commonly dip at 45° SW whereas the broad upright limb has an overall dip of 30° SW. Plates 4 and 11 give natural, near down-plunge views of the fold at the level of the Cadomin and Kennedy seam along Drummond and Prospect Creeks, respectively.

Two sets of mesoscopic folds were observed in the Drummond Creek thrust sheet, one in the Luscar Formation, defined by mine data, the other by outcrops of Mountain Park strata. The fold axis and axial plane orientations of the former folds are 134/15 and 230/67 whereas the fold axis of the outcrop folds is 133/17. These two sets of folds may be one and the same as a syncline in the mine workings southwest of the folds apparent in Figures 4 and 9 at -12 000 east and 3 000 north when connected to the outcrop syncline yields a reasonable axial plane orientation of 218/68.

Prospect Creek thrust sheet

The Prospect Creek thrust sheet is wedge-shaped, being 7 km wide along Drummond Creek and terminating in the Blackstone Formation east of MacKenzie Creek where the Drummond Creek and Prospect Creek thrusts merge. It exposes Nikanassin, Cadomin, Mountain Park and Blackstone strata.

Prospect Creek thrust

The Prospect Creek thrust is readily discernible along Prospect Creek through duplication of the Cadomin Conglomerate. Half a kilometer northwest of this creek the fault truncates this formation in the footwall to enter the Nikanassin Formation. Outside the area studied, along Harlequin Creek which parallels Drummond Creek 3.5 km to the northwest, the thrust is apparently situated in the Fernie Group and merges with the McConnell thrust. To the southeast the fault gradually cuts up section, truncating the Cadomin in the hanging wall and the Kennedy seam in the footwall along Thornton Creek. Just east of the McLeod River, former mine workings and borehole data demonstrate that the thrust divides into two major splays and has undergone folding. These splays reconnect to the east where the fault enters the Blackstone Formation. Beyond MacKenzie Creek the fault is not traceable, but it probably merges with the Drummond Creek thrust since the overlying Cardium Formation remains unfaulted for a distance of 7 km southeast of MacKenzie Creek.

Since the surface trace of the Prospect Creek fault is sub-parallel to the traces of the Cadomin Formation in both the hanging wall and footwall, the fault must be nearly parallel to bedding. Using the points of truncation of the Cadomin, Kennedy seam and Nikanassin Formation the angles between the fault and bedding in the footwall and hanging wall west of the McLeod River were found to be 7° and 6°, respectively. A displacement of about 2 km was calculated using the profile positions of the truncations of the Cadomin Formation in the hanging wall and footwall.

The thrust sheet

Strata within the Prospect Creek thrust sheet have been folded at several localities and one small fault was observed. The Harris Mountain anticline and syncline, while dominantly in the Harris Creek unit, affect this thrust sheet near Harris Mountain are discussed in more detail on pages 70 to 71. Other structures include the Prospect Creek anticline and syncline, an intervening small fault and fold-pair, the East Pit anticline and syncline and the faults associated with the Harris Mountain horse.

The Prospect Creek anticline is a broad feature with an apical angle of approximately 150°. This inclined plunging fold has a fold axis orientation of 130/10 and while hard to discern from orientations on a map is visible in profile view (Fig. 14 and Plate 4). A small thrust fault located on the north limb of the syncline cuts up section at 30° and displaces the Cadomin approximately 100 m. A short distance to the north of this fault along Drummond Creek a small overturned anticline-syncline pair deforms the Cadomin (Plate 4). These three structures are not recognized to the east and are believed to die out in a short distance. The Prospect Creek Syncline is well defined, folding Nikanassin, Cadomin and Luscar strata of the Prospect Creek thrust sheet as well as strata of the Drummond Creek thrust sheet as high as the Blackstone Formation. This fold is upright-plunging with a fold axis orientation of 130/10.

Between Prospect Creek and the McLeod River strata of the Prospect Creek thrust sheet form a homocline with a mean orientation of 200/30 (Plate 9).

East of the McLeod River the East Pit anticline and syncline are exposed in the East Pit. These folds which terminate to the northwest against the Prospect Creek thrust affect strata as high as the Blackstone in the overlying Drummond Creek thrust sheet. Orientations of 135/10 for the fold axis and 220/67 for the axial plane were obtained from the mine workings, both surface and underground. A detailed description of the East Pit is given on page 80.

A large complex horse containing the Kennedy seam has been defined by drilling north of the East Pit (Fig. 15). The Prospect Creek thrust which underlies the horse has a displacement of about 1.4 km and cuts up section to the northeast at approximately 3° in both the hanging and footwall. The uppermost splay has a displacement of approximately 0.6 km with a mean bedding to fault angle of near 90° in the footwall and approximately 10° in the hanging wall.

Harris Creek thrust sheet

The Harris Creek thrust sheet maintains a width of about 1.5 km across the entire map area except in the east where the Harris Creek thrust begins to merge with the

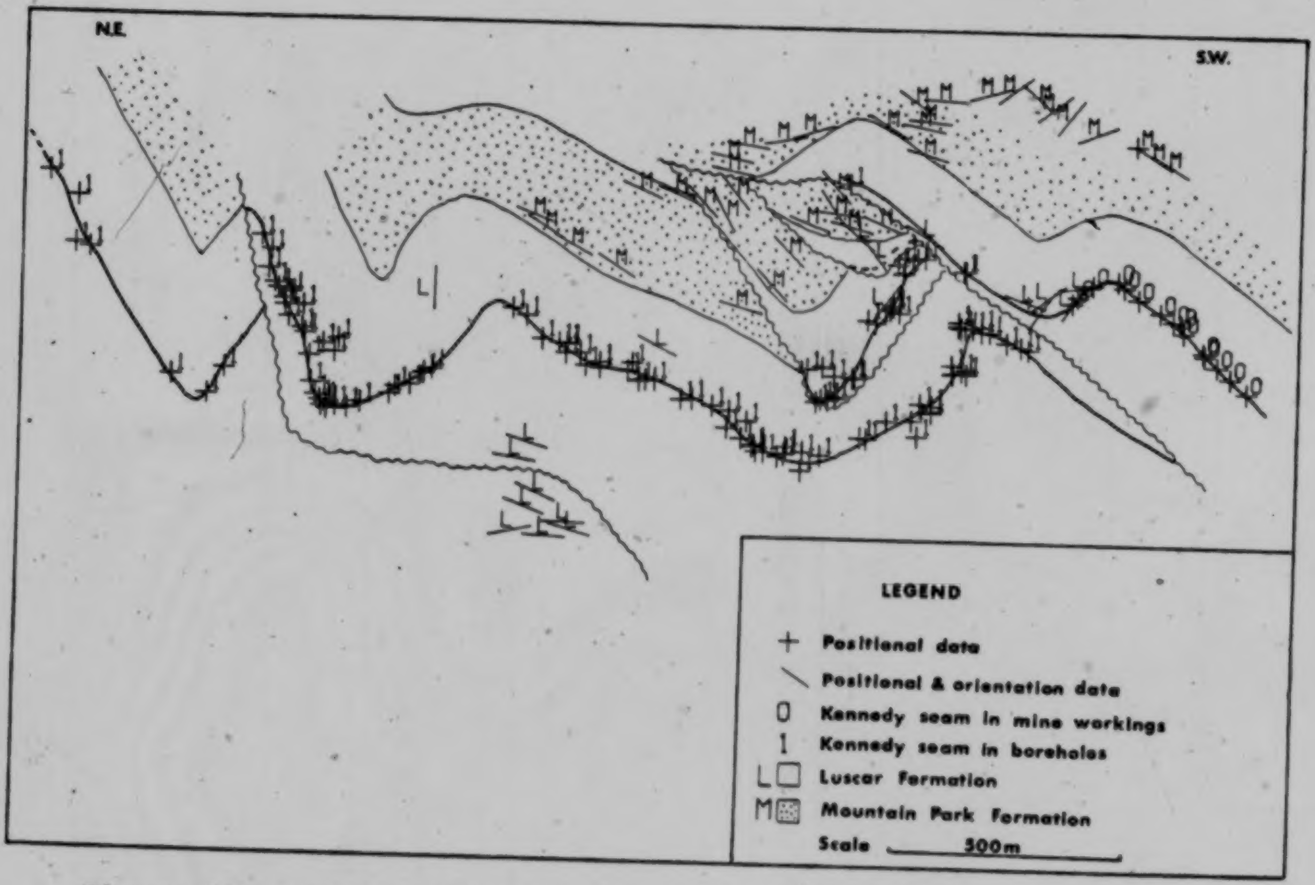

N.E.
S.W.
LEGEND
+ Positional data
\ Positional & orientation data
0 Kennedy seam in mine workings
I Kennedy seam in boreholes
L ☐ Luscar Formation
M ▨ Mountain Park Formation
Scale 500m

Figure 15. Interpreted computer produced plot of the structure at Harris Mountain.

Prospect Creek and Drummond Creek thrusts. Nikanassin, Cadomin, Luscar, Mountain Park and Blackstone strata are contained within the thrust sheet, the older formations being confined to the west and the younger to the east.

Harris Creek thrust

Between the McLeod River and Harris Creek the Harris Creek thrust duplicates the Cadomin Formation. To the east of the Cadomin duplication the fault slowly cuts up section, duplicating the Kennedy seam near MacKenzie Creek. At the eastern boundary of the map area the fault is near the top of the Luscar Formation. Small bedding to fault angles are assumed as the fault trace is sub-parallel to the surface traces of the Cadomin and Kennedy seam. A displacement of the Cadomin Formation in the order of 0.5 km is apparent from profile views.

The thrust sheet

The unit contains several structures which affect the overlying unit such as the Harris Mountain anticline and syncline but also contain several structures which are unique to the unit.

The Harris Mountain anticline affects strata from Nikanassin to Luscar. It has a mean fold axis orientation of 210/3 with a 5° plunge west of Cheviot Creek and a 2° plunge east of Cheviot Creek. The axial plane is believed to be nearly vertical.

A rotational fault occurs in the northeast limb of the Harris Mountain anticline. The fault which appears to dip to the southwest separates the hinge zone of the anticline from the highly disturbed strata in the core of the Harris Mountain syncline between Prospect Creek and the McLeod River (Fig. 13). In the northwest the fault thrusts Nikanassin and Cadomin strata over the Luscar Formation whereas in the east it superimposes Luscar strata on the Nikanassin and Cadomin Formation. Varying fold axis orientations in the folds to either side of the fault substantiate the rotational concept.

The Harris Mountain syncline is the largest structure in this unit affecting strata from the Nikanssin to Mountain Park Formations. In the west, along Prospect Creek, the fold is developed in Nikanassin strata and is upright-plunging with a fold axis orientation of 130/10 and a vertical axial plane. As the fold is traced eastwards younger strata become involved and the fold becomes more complex; at the level of the Cadomin Formation it has split into two synclines and an anticline with orientation for the fold axis and axial planes of 125/5 and 210/50, respectively. The overturned anticline and syncline either die out or merge with the main syncline as they are traced up section to the east. One broad syncline is present at the height of the Kennedy seam where orientations for the fold axis and axial plane of 125/15 and about 210/80, respectively were obtained. The fold also affects the Prospect Creek thrust along with the Luscar and Mountain Park strata in its hanging wall.

The Harris Mountain thrust fault just north of and parallel to the westerly flowing section of the McLeod River duplicates the Cadomin and separates the highly disturbed core area from the north limb of the Harris Mountain syncline. To the east the fault cuts up section at a low angle being folded by the Harris Creek anticline and syncline before duplicating the Kennedy seam. Further east it is responsible for the major duplication of the Mountain Park Formation before entering the Blackstone Formation 2 km east of MacKenzie Creek. The displacement along this fault increases from west to east due to the absorbtion of the displacement associated with the distorted strata in the Harris Mountain syncline. To the west the fault is believed to parallel bedding near the base of the Nikanassin Formation.

To the north of the Harris Mountain syncline the Harris Creek anticline-syncline pair occur, deforming strata from

Nikanassin to Mountain Park. The folds are associated with the Harris Creek thrust, originating where the Cadomin is truncated in the footwall of the fault. Deformed Cadomin strata are well exposed along the north-south tributary to the McLeod River where a fold axis and axial plane orientation of 130/20 and 25/80 were obtained. The syncline and anticline are well defined at the level of the Kennedy seam by borehole intersections.

MacKenzie Creek thrust sheet

The MacKenzie Creek structural unit contains those strata in the footwall of the Harris Creek thrust and in the hanging wall of the MacKenzie Creek thrust. Strata from the pre-Jurassic map unit up to the Mountain Park Formation in the map area have been affected by structures in this unit. The unit is open at both ends where mapping is less detailed or outcrop lacking.

MacKenzie Creek thrust

The MacKenzie Creek thrust is readily discernible as it duplicates the Cadomin Conglomerate along MacKenzie Creek. The fault while not mapped in detail west of MacKenzie Creek is believed to be present, though undetected, in the

Nikanassin Formation west of the small anticline-syncline pair at 10 000 east and 14 000 north. The fault which has an orientation of 230/40 near MacKenzie Creek, has a displacement of 0.5 km determined from profile measurements assuming movement to have been perpendicular to the fold axis. A marked steepening of strata from the hanging wall to the footwall of approximately 10° is seen across the fault. The eastern extension of the fault beyond 22 000 east is poorly defined due to a lack of exposure.

The thrust sheet

The dominant structures of this unit are an anticline-syncline pair which originates in the pre-Jurassic map unit and affects strata as young as the Blackstone Formation. Two faults cause minor duplication of the Cadomin and surrounding strata in the southern limb of the anticline. In the northern limb of the syncline a small fault is seen to duplicate the Kennedy seam in a borehole while several gentle folds were noted in outcrop. Some highly deformed strata associated with the MacKenzie Creek fault are seen along MacKenzie Creek.

Two small thrusts evident from the duplication of the Cadomin are located to the northeast of Harris Mountain on the south limb of the Cadomin Mountain anticline. The southern has an orientation of 210/40 and a displacement of approximately 100 m. The other fault has an orientation of 200/30 and a displacement of approximately 100 m. Both faults are lost to the east where they likely merge and result in the duplication of the Kennedy seam before merging with the Harris Creek thrust. To the west due to lack of mapping they cannot be traced for more than one or two kilometers.

The Cadomin Mountain anticline and syncline traceable from bedding orientations and aerial photographs can be traced for 9 km along a northwest-southeast trend. In the west along the McLeod River these folds are present as a structural terrace in the pre-Jurassic map unit (Plate 1). An axial plane orientation of approximately 40/80 was obtained for this section. The axial planes become southwesterly dipping when traced to the southeast. At the level of the Cadomin Formation an orientation of 220/50 was obtained accompanied by a fold axis orientation of 130/10. Further to the southeast the folds affect the Kennedy seam and Mountain Park and Blackstone Formation. A fault which duplicates the Kennedy seam along MacKenzie Creek although not noted in outcrop is evident in a borehole log which shows a stratigraphic throw of 32 m. A minor anticline-syncline pair were noted along Swaren Creek above the Cadomin to the east of MacKenzie Creek. While insufficient data were available for an accurate fold axis determination field evidence points to the folds plunging to the southeast at approximately 20°.

Kryczka thrust sheet

The Kryczka structural unit contains strata from the pre-Jurassic map unit to the Mountain Park Formation. The unit is bounded by the MacKenzie Creek thrust to the southwest and the Kryczka thrust to the southeast. Minor folds and some small displacement faults are the only irregularities in the otherwise homoclinal structure.

The Kryczka thrust

The thrust noted by Kryczka(1959) along MacKenzie Creek is seen to duplicate and triplicate the Cadomin Formation to the east of MacKenzie Creek (MacKay, 1929). To the west the fault probably merges with the MacKenzie Creek fault or cuts down into the Fernie Formation. An orientation of approximately 220/40 for this fault is obtained from map interpretation.

The thrust sheet

While strata as low as the pre-Jurassic unit were investigated only the Luscar and Cadomin Formations were studied to any extent. Several folds associated with the

MacKenzie Creek thrust occur along MacKenzie Creek a short distance to the northeast of this fault. A small fault and associated folds were noted in the central portion of the area while moderate scale folds were noted in the far eastern reaches of the unit.

A small symmetrical anticline about 200 m north along MacKenzie Creek from the MacKenzie Creek fault has a fold axis orientation of 307/10 and a vertical axial plane. This unusual orientation is likely due to uncharacteristic deformation associated with the fault. Other strata in the vicinity of this fold are complexly deformed but assume the common southwesterly dip a short distance to the north. In the central portion of the area a small thrust with an orientation of 220/30 and a small fold with a fold axis orientation of 146/11 were noted along the east-west stream traverse. At the eastern end of the unit an anticline and syncline pair is present. The folds are significant, with a wavelength of 635 m and dips in the common limb of up to 70°. Although not recognized in outcrop the folds are certain to affect the Kennedy seam causing it to wrap around these structures. These folds also explain the excessive Luscar section in this region.

Mesoscopic Structures

Mesoscopic structures not described in the above sections were mapped and recorded whenever encountered. Four types of mesoscopic data were collected: (1) bedding measurements across mesoscopic folds, (2) joint orientations from three formations at three localities, (3) data from a detailed study of the East Pit and (4) fault and slickenside striae.

Mesoscopic fold data were computerized and stored in MP.AXIS. Figure 16 illustrates the positions and orientations of these structures. Several of the folds plunge to the west but the majority are oriented approximately parallel to the mean macroscopic fold axis orientation for the area of 135/15. The mean orientation of the mesoscopic folds is 125/13 with a standard scattering angle of 16.6°. Although not quantitatively analysed, in general the axial planes of these folds dip southwest. Many mesoscopic folds appear to be drag folds closely associated with thrust faults. As such their orientation reinforces the belief that faulting and folding in the Mountain Park area occurred under the same stress system.

Joints with surface areas in excess of 10 sq m were obtained from strata at 3 localities and from 3 stratigraphic intervals. A total of 337 measurements were

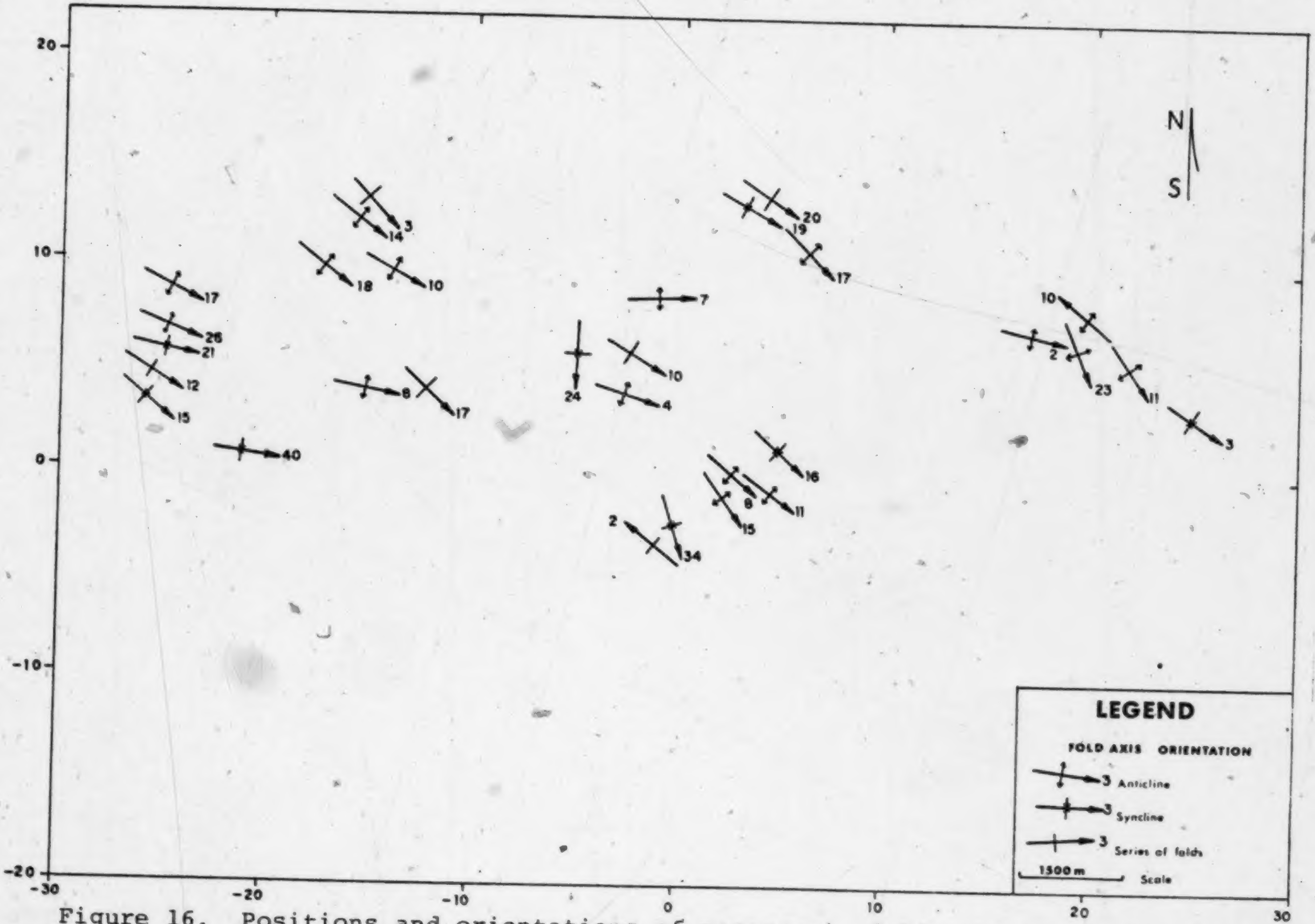

N
S
LEGEND
FOLD AXIS ORIENTATION
3 Anticline
3 Syncline
3 Series of folds
1500 m
Scale
20
10
0
-10
-20
-30
-20
-10
0
10
20
30
17
26
21
12
15
40
3
14
18
10
8
17
24
10
4
7
20
19
17
2
34
8
15
11
16
10
2
23
11
3

Figure 16. Positions and orientations of mesoscopic fold axes in the map area.

Plate 13. Well jointed Cardium sandstones in southern part of map area. Hatchet approximately 40 cm.

taken from the Cardium Formation, Luscar Formation and the pre-Jurassic map unit (Plate 13). In order to compare the joints, orientation diagrams of the poles to joint planes were produced with the orientations rotated so that in all cases the associated bedding planes were horizontal. Figure 17 displays the rotated and unrotated orientation diagrams for the three joint measurement localities. In all cases the joints were normal to bedding. In the Cardium and pre-Jurassic units two well defined joint sets emerged whereas in the Luscar of the East Pit 4 sets were found.

The East Pit, 6 000 sq m in area, was studied in detail, and 58 data stations were plane tabled. The data were stored in the MPEP file. Three map units were used in the study (1) hanging wall, (2) footwall and (3) Kennedy seam. Two folds, called the East Pit anticline and syncline

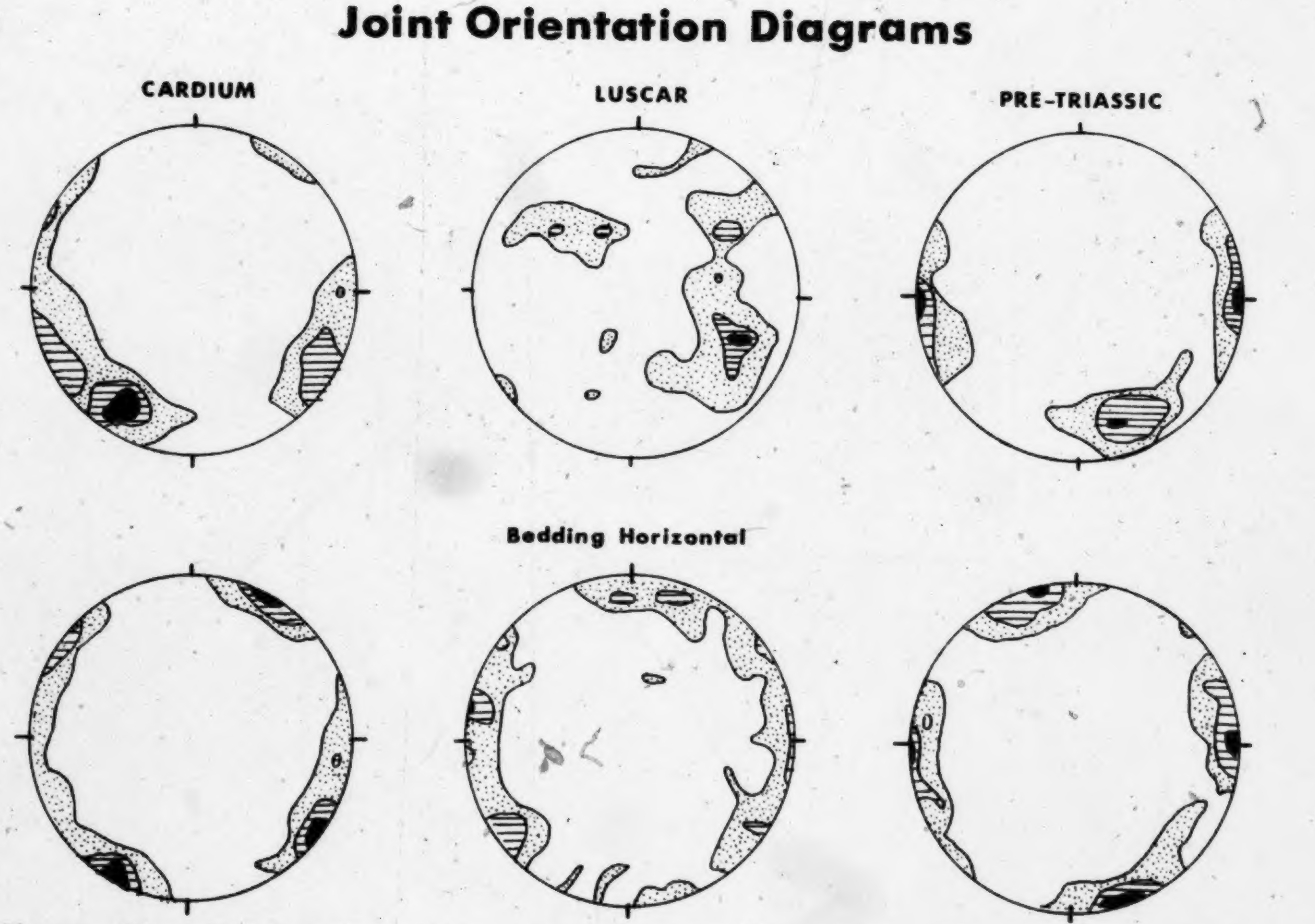


Figure 17. Joint orientation diagrams. Contour intervals are 1-5%, 6-10% and greater than 10%.

(see p. 62), are exposed in the pit. Plates 14 and 15 show

Plate 14. Looking southeast at the Kennedy seam on the crest of the East Pit anticline. Note extreme deformation.

the style of deformation associated with these folds. Plate 14 illustrates the extremely complex structure which commonly occurs in the axial region of folds in coal-bearing areas. Plate 15 illustrates the reactivated joints which are the most striking structures in the East Pit. The joints which show no displacement but are fully developed near the syncline have increased displacement as they near the crest of the anticline. The constant joint to bedding angle and varied displacement along joints suggest that the joints were formed before this small scale folding occurred which later resulted in the displacement of the joints near the anticline. Appendices 3(f) and 3(d) contain a map of the data stations and orientations as well as a profile plot of

Plate 15. Looking along the intersection of joints and Kennedy seam footwall on crest of East Pit anticline in the pit.

the two folds. Old mine workings below the pit gave a more reliable mean fold axis orientation of 135/10 than the directly measured surface exposures due to the disturbed nature of the strata exposed in the pit. The exposure in the East Pit is the most complex seen in the whole area, due to the excellent exposure and should not be considered as a unique structure.

Some fault and associated slickenside striae orientations were recorded but in such quantities as not to warrant any quantitative analysis. The inability to obtain field measurements on fault planes was due to their near bedding plane attitude which caused them to be very hard to detect.

Discussion

Two excellent marker horizons, the Cadomin Formation and Kennedy seam, provide stratigraphic markers with which one may determine the deformational history of the Mountain Park area. The dominant structures are thrust faults. Faulting generally progressed in a northeasterly direction with movement along younger faults causing folds in the overlying faults and strata. Directions of displacement associated with these thrusts are to the northeast. The thrusts apparently enter zones of decollement in the Blackstone Formation to the east and in the lower Nikanassin to the west. Large faults such as the Miette and Fiddle River thrusts are likely to be extensions of several of the faults in the study area. Small fault to bedding plane angles characterize the faults which commonly have displacements exceeding 1 km. Folds are closely associated with the thrust faulting and have a mean fold axis orientation of 135/15 which is parallel to the line of intersection between faults and bedding.

CONCLUSIONS

After 3 months in the field and 14 in the laboratory, all the major objectives of the study have been realized. The computer has been used effectively to store, retrieve and process many of the surface and subsurface data accumulated. The thicknesses of the Luscar and Mountain Park Formations have been revised from 490 m to 380 m and from 120 m to 200 m, respectively, and the number of significant coal seams in the Luscar reduced from 11 to 4. These seams are thought to be much more extensive than previously envisaged; one seam has been correlated all the way from Nordegg, Alberta into northeastern British Columbia. Instead of the six steeply dipping thrust and normal faults with displacements of about 0.5 km that were mapped by MacKay (1929), the Mountain Park area is now thought to be crossed by five thrust faults that cut up section to the northeast at about 5° to bedding and that have a cumulative displacement of about 10 km. These faults, which appear to be splays from the McConnell and Miette thrusts, flatten and merge in the Blackstone Formation. The structure of the area is illustrated by a geological map at a scale of 1:25 000 and by cross sections constructed using a computerized down-plunge projection technique.

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APPENDIX 1

Formats and Partial Listings of the O/C,MP.AXIS,MPDH,MPMW and MPEP Files Used to Store Data.

(a) The O/C File

Format

Column	Data
1-3	Identification number.
6-11	Northing or y coordinate.
13-18	Easting or x coordinate.
20-23	Elevation or z coordinate.
25	Alphabetic code designating stratigraphic position: K= Cardium Formation B= Blackstone Formation E= Mountain Park-Blackstone contact M= Mountain Park Formation L= Luscar Formation C= Cadomin Formation N= Nikanassin Formation F= Fernie Group P= Pre-Jurassic (undivided)
27	Binary code indicating whether or not significant uncodeable information occurs on field data sheet: 1= Yes 0= No
29	Numeric code indicating confidence in outcrop coordinates. Scale from 1 to 9 being extremely accurately located to poorly located, respectively.
31	Number of bedding plane orientations recorded.
33-53	Dip directions of bedding.
55-75	Dips of bedding.
76-83	Mean dip direction and dip obtained after processing above readings (see p. 21).
84-93	Concentration parameter, specifying scatter of original measurements of bedding about mean, obtained after processing above readings (see p. 22).

POOR COPY

Partial Listing

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[illegible]  [illegible] 5720   [illegible]1.9267   0230360320322033    197. 26.    72.37
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(b) The MPDH File

Format

Column	Data
1-5	Identification number. To facilitate handling, original designations of some holes in records of Consolidation Coal Company of Canada have been altered. Whereas M.P.West holes retain their original numerical designations, 500 has been added to those of M.P.East holes. Decimals have been used to identify separate holes drilled at same location.
7	Alphabetic code designating horizons picked: S= Topographic surface A= Base of Kennedy(a) seam B= Base of Kennedy(b) seam C= Base of Thornton seam D= Base of ST1 (probably Michelin or Thornton) seam F= Base of Michelin seam G= Base of Cheviot seam
9-14	Northing or y coordinate.
16-21	Easting or x coordinate.
23-26	Elevation or z coordinate.
28	Alphabetic code designating sources of information used to identify horizon picked: A= Gamma, resistivity and driller's logs B= Gamma and resistivity logs C= Gamma and driller's logs D= Resistivity and driller's logs E= Driller's logs F= None of the above
30	Binary code indicating identification reliability: 0= Excellent 1= Good

Partial Listing

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145.0 S    4906 -16235 6113 A 0
160.0 S    4929 -16041 6088 A 0
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 50.0 A    4656 -16037 5921 A 0
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144.0 B    4774 -15934 5977 A 0
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 12.0 A    6033 -15036 5896 A 0
 18.3 A    6175 -14996 5972 A 0
 18.3 B    6175 -14996 5961 A 0
 18.3 S    6175 -14996 6040 A 0
 14.0 S    4673 -14984 6061 A 0
 14.0 B    4673 -14984 5970 A 0
 14.0 A    4673 -14984 5984 A 0
 18.1 B    5864 -14817 5947 A 0
 18.1 A    5864 -14817 5927 A 0
 18.1 S    5864 -14817 6037 A 0
```

(c) The MPMW File

Format

Column	Data
1-4	Identifications number.
6-11	Easting or x coordinate.
13-18	Northing or y coordinate.
20-23	Elevation or z coordinate.
25	Binary code indicating whether Kennedy seam is in hanging wall or footwall of Drummond Creek thrust. Author's Kennedy seam is referred to on mine plans as "Kennedy seam" in hanging wall and "#3 seam" in footwall: 0= Footwall 1= Hanging wall
27	Binary code indicating whether data station is underground or at surface: 0= Underground 1= Surface
29	Binary code indicating whether or not orientation data are available: 0= No 1= Yes
31-36	Dip direction and dip of bedding.

Partial Listing

```
2046    1307  - 8650 5709 1 0 1 093020
2047    1152  - 9210 5714 1 0 1 113035
2048    1313  - 9230 5716 1 0 1 222050
2049    1405  - 9375 5718 1 0 1 119047
2050    1635  - 9698 5720 1 0 1 215050
2051    1891  -10135 5724 1 0 1 194037
2052    1945  -10280 5726 1 0 1 206030
2053    2073  -10530 5729 1 0 1 206035
2054    2317  -10928 5734 1 0 1 205028
2055    2425  -11097 5737 1 0 1 213025
2056    2605  -11452 5741 1 0 1 205022
2057    2676  -11630 5743 1 0 1 200020
2058    2863  -12133 5748 1 0 1 195020
2059    2832  -12437 5757 1 0 1 183023
2060    2625  -12545 5759 1 0 0
2061 - 1360       85 5555 0 0 0
2062 - 1435       12 5545 0 0 0
2063 -  866       37 5669 0 0 0
2064 -  312 -     11 5918 0 1 0
2065 -  312       14 5522 0 1 0
2066 - 1359      244 5552 0 0 0
2067 - 1340      281 5552 0 0 0
2068 - 1271      280 5554 0 0 0
2069 - 1264      375 5554 0 0 0
2070 - 1304      502 5556 0 0 0
2071 - 1338      615 5557 0 0 0
2072 - 1294      770 5557 0 0 0
2073 - 1284      867 5559 0 0 0
2074 - 1286      963 5559 0 0 0
2075 - 1276     1070 5559 0 0 0
2076 - 1242     1129 5560 0 0 0
2077 - 1198     1123 5560 0 0 0
2078 - 1091     1058 5563 0 0 0
2079 - 1026     1044 5564 0 0 0
2080 - 1056     1117 5566 0 0 0
2081 - 1074     1175 5567 0 0 0
```

(d) The MPEP File

Format

Column	Data
	First line
1-3	Identification number: 1-51 for data stations and 501-507 for survey turning hubs.
5-10	Northing or y coordinate.
12-17	Easting or x coordinate.
19-22	Elevation or z coordinate.
24	Code designating map unit: 1= Footwall 2= Footwall - coal interface 3= Coal 4= Hanging wall - coal interface 5= Hanging wall
26	Number of bedding plane orientations recorded.
28-42	Dip directions of bedding.
44-58	Dips of bedding.
60	Number of joint orientations.
62-79	Dip directions of joints.
	Second Line
1-18	Dips of joints.

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Partial Listing

```
  1    12     47    4 2 5 040047012051052 042074001072074 2 308135
105027
  2    -42   -22   10 2 5 042042022047040 070740713675077 4 321122144309
035025120073
  3    -41     2    4 2 5 [illegible]2051013047053 075071005047055 2
  4    -22   -21   14 2 5 044045042045043 025000000072074 1 316
076
  5    -4    -42   13 2 5 [illegible]40044[illegible]4[illegible]040044 052093007070093 4 129124130121
[illegible]038058034041
  6    17    -47   23 2 5 042043035037035 037077070003071 4 292140135296
017020042015
  7    42    -44   35 2 5 052047040041035 030077070050071 1 131
.31
  8    72    -44   22 2 3 175177172142187 042040059057065 1 312
.77
  9    61    -25   15 2 5 154196195196197 054049049046045 6 30433634211029729
074039040076050037
 10    52     12   14 1 5 103178102131177 033026040041036 0
 11    61      7   27 1 5 141207193143171 038078050040037 0
 12    92      2   30 2 5 100342100175101 041030032035030 0
 13    7.    -22   29 1 5 175177174172167 041049044051039 2 311236
449049
 14    4      55   40 4 5 1[illegible]7210202203100 054049043043047 3 023030201
037023032
 15    4.     62   32 3 5 167204152133190 025034035045031 0
 16    17     27   22 3 3 121128129130125 041041048044039 0
 17   -49    101   15 5 5 058058085065092 038036043044041 5 326320213267213
049049054022050
 18    43   -119   56 2 5 051050048047044 049064060068074 0
```

(e) The MP.AXIS File

Format

Column	Data
	First line
1-3	Identification number.
5-10	Easting or x coordinate.
11-16	Northing or y coordinate.
17-22	Elevation or z coordinate.
24	Binary code indicating whether or not orientation data from this outcrop are in O/C file: 0= No 1= Yes
26	Numeric code indicating type of folding present: 1= Anticline 2= Syncline 3= Series of folds
28	Alphabetic code designating stratigraphic position (see description of column 25 of O/C file).
30-31	Number of bedding plane orientations.
33-80	Bedding plane orientations in an integrated format with dip directions interspersed with dips.
	Second line
1-42	As in columns 33-80 of first line.
45-50	Trend and plunge of best-fit fold axis obtained after processing above readings (see p. 21).

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Partial Listing

```
516  21787  3446  5505 0 1 L  5 001047070[illegible] 0950101550131900[illegible]
                                          146011
494  19441  4775  5456 0 1 L  3 2400272[illegible] 10024011010010020054
                                          307010
730  19216  [illegible]  [illegible] 1 1 F  5 [illegible]111025704912752017503[illegible]
                                          157023
492  [illegible]  [illegible]  [illegible] [illegible]  0 1[illegible]
                                          103002
[illegible]  -[illegible]  5[illegible]  [illegible] 1 2 L  2 17101315102715305111204309054
                                          101024
[illegible]  -2[illegible]  3072  5710 [illegible] 1 [illegible]  0 0[illegible]0370411920131440112020[illegible]32
                                          122000
207  -2470  3024  5703 1 2 L  6 2050421930316990102340518270900201[illegible]
                                          119012
722  -2297  4[illegible]  5713 1 1 L 10 19700719100202008154095131104197040187027042005
029033023049
                                          107004
427  -2104  5524  5896 0 1 2 12 0300640250200380700410050470570410490440270600009
221051[illegible]230[illegible]116003011802[illegible]
                                          128003
505  -1304  7172  5770 1 1 K  6 1550140730071570131390131450101400[illegible]
                                          087007
725  -466  -2605  5900 0 2 F  4 00713307500009605919564[illegible]2
                                          162034
721  -721  -3466  5956 0 3 8 10 2190132130050340430400700330270280300310052[illegible]0008
231002702023
                                          307002
302  2130  -1114  0305 0 1 F  5 1040201250131340131250141400[illegible]19
                                          140015
718  2765  100  6050 0 1 L 11 149005076007075024055033055030047024403112104963[illegible]
04204504030505205[illegible]
                                          130006
357  3049  13301  7225 0 3 8 14 1[illegible]01301760301750301700301210230630301370256540[illegible]
045[illegible]
                                          123026
377  [illegible]  -[illegible]  [illegible] 0 1 E  3 1[illegible]20111300131920[illegible]10562320304[illegible]
                                          120011
35[illegible]  [illegible]  [illegible]  71[illegible] 0 2 [illegible] 11 1[illegible]
[illegible]
                                          120015
3[illegible]  [illegible]  [illegible]  [illegible]  0 [illegible]
                                          132010
```

APPENDIX 2

Retrieval Programs, Run Commands and the AR-File

Source Listing of the Program STATION

```
C******** DESIGNED TO EXTRACT SPECIFIED OUTCROPS AND PUT THE PERTINANT
C         INFORMATION IN A FORMAT AMENABLE TO CYLTEST, ETC.
      INTEGER STA,ST,X,Y,Z,F,DD,D
      INTEGER SLASH/'/'/
      INTEGER CODE/'*'/
101   READ(1,10,END=51)STA
100   READ(5,11,END=52)ST,Y,X,Z,F,DD,D
      IF(STA .NE. ST)GO TO 50
      X=X+32000
      Y=Y+16000
      IF(D .LT. 90)  GO TO 1
      DD=DD+180
      IF(DD .GT. 360)  DD=DD-360
      D=90-(D-90)
      WRITE(6,14)F,X,Y,Z,DD,D,CODE,ST
      GO TO 53
1     WRITE(6,12)F,X,Y,Z,DD,D,ST
      GO TO 53
 52   CONTINUE
      REWIND 5
53    CONTINUE
      GO TO 101
 50   CONTINUE
      GO TO 100
 51   CONTINUE
      WRITE(6,13)SLASH
 10   FORMAT(I3)
 11   FORMAT(I3,2X,I6,1X,I6,1X,I4,1X,A1,50X,I3,1X,I3)
 12   FORMAT(A1,I5,I5,I5,1X,I3,I3,5X,I3)
 13   FORMAT(A1)
14    FORMAT(A1,I5,I5,I5,1X,I3,I3,1X,A1,3X,I3)
      STOP
      END
```

Source Listing of the Program COALADD

```
C*****COALADD READS THE MPDH FILE AND THE USER
C      INPUT LIMITS OF INTEREST TO PRODUCE A FILE OF
C      BORE-HOLE INTERSECTIONS WHICH CAN BE ADDED TO AN
C      AR-FILE.
C
C
       INTEGER CODE,X,Y,Z,COAL/'A'/,NEWCO/'1'/,XMIN,XMAX,
      *YMIN,YMAX
       READ(6,10)XMAX,XMIN,YMAX,YMIN
       DO 1 I=1,1000
       READ(5,11,END=9)CODE,Y,X,Z
       IF(CODE .NE. COAL)  GO TO 1
       IF(X .LT. XMIN)  GO TO 1
       IF(X .GT. XMAX)  GO TO 1
       IF(Y .LT. YMIN)  GO TO 1
       IF(Y .GT. YMAX)  GO TO 1
       X=X+32000
       Y=Y+16000
       WRITE(7,12)NEWCO,X,Y,Z
1      CONTINUE
10     FORMAT(4I10)
11     FORMAT(6X,A1,2(1X,I6)1X,I4)
12     FORMAT(A1,3I5)
9      STOP
       END
```

Source Listing of the Program COALADD1

```
C***** COALADD1 READS THE MPMW FILE AND THE USER
C       INPUT LIMITS OF INTEREST TO PRODUCE A FILE
C       OF COAL OCCURENCES LOCATED IN OLD MINE-WORKINGS
C       WHICH CAN THEN BE ADDED TO AN AR-FILE.
C
C
      INTEGER CODE,X,Y,Z,DD,DI,XMAX,XMIN,YMAX,YMIN
      READ(6,10)XMAX,XMIN,YMAX,YMIN
      DO 1 I=1,1000
      READ(5,11,END=9)Y,X,Z,CODE,DD,DI
      IF(X .GT. XMAX)  GO TO 1
      IF(X .LT. XMIN)  GO TO 1
      IF(Y .GT. YMAX)  GO TO 1
      IF(Y .LT. YMIN)  GO TO 1
      X=X+32000
      Y=Y+16000
      WRITE(7,12)NEWCO,X,Y,Z
1     CONTINUE
10    FORMAT(4I10)
11    FORMAT(5X,I6,1X,I6,1X,I4,1X,A1,5X,2I3)
12    FORMAT(A1,3I5,1X,2I3)
9     STOP
      END
```

Run Commands for STATION, COALADD and COALADD1

Run sequence

```
#$RUN STATION 1=*MSOURCE* 5=O/C 6=-OUTPUT1
  (user types in required station numbers in I3 format)
#$RUN COALADD 1=*MSOURCE* 5=MPDH 6=-OUTPUT2
  (user types in the X and Y limits in 4I6 format)
#$RUN COALADD1 1=*MSOURCE* 5=MPMW 6=-OUTPUT3
  (user types in the X and Y limits in 4I6 format)
#$COPY -OUTPUT1+-OUTPUT2+-OUTPUT3 TO -OUTPUT4
  (stores outcrop, mine and bore-hole data in -output4)
#$EDIT -OUTPUT4
:INSERT .5
?2 DOMAIN 15
?
:RENUMBER
:STOP
#$GET -OUTPUT4
#READY
#$NUMBER LAST+1
#     21_/
#     22_$UNNUMBER
```

Format of the AR-File Produced by STATION, COALADD and COALADD1

Column	Data
	First line
1	Numeric code specifying type of orientation data in file: 1= Trend and plunge 2= Dip direction and dip
3-40	Title
	Second to second last lines
1	Code designating stratigraphic position. Numeric codes 0 and 1 were used for Kennedy seam in mine workings and borehole intersections, respectively, whereas alphabetic codes described in column 25 of O/C file were used to designate formations at outcrops.
2-6	Easting or x coordinate.
7-11	Northing or y coordinate.
12-16	Elevation or z coordinate.
18-20	Mean dip direction.
21-23	Mean dip.
25	A blank or an asterisk indicating that strata are right way up or overturned, respectively. Thus an orientation of 219/88 with an asterisk is in reality 39/92.
26-29	Station number. These columns were left blank when data came from MPDH,MPMW and MPEP files.
31	Number of orientation readings.
32-41	Concentration parameter.
46-52	Single measurement of bedding randomly selected from O/C file, required in a cylindricity test (see p. 25).
	Last line
1	Slash indicating end of file.

Example of an AR-File

```
2 DOMAIN 15
M3355913724 6000  48 59     29 5       59.52       46  59
M3310013749 5970  51 56     30 5      138.44       55  57
M3290513854 5955  51 56     33 5       85.86       64  60
M3277313890 5945 219 88  *  34 5      120.46       35  98
M3267313903 5935  46 76     35 5      111.26       55  77
M3217113972 5920 213 78  *  36 5       16.34       39  77
M3184014338 5885  64 26     37 5      429.74       76  25
M3121912520 5950  37 31     38 5      139.96       39  33
B3140911999 6000  38 44     39 5      145.35       41  52
M3122012784 5915  45 56     40 5      633.45       45  56
M3132912971 5910  52 53     41 5      155.13       45  51
M3156913295 5925  93 13     42 5      133.60       79  21
M3153413391 5900  77 31     43 5      169.75       69  33
03208514640 5555
03201214565 5545
03203715134 5669
03198915686 5918
03208415866 5922
13738420868 5627
13747220929 5700
13765121019 5832
13827520783 5845
13827520706 5733
13829422212 5957
13830722092 5907
13999721462 5660
14001121616 5868
```

APPENDIX 3

Programs and Procedures used in the Processing of Structural Data

(a) Program EIGENMEAN

```
C***** THIS ROUTINE IS TO BE USED TO FIND THE EIGEN VECTORS
C      ASSOCIATED WITH THE MAXIMUM EIGEN VALUE. THE SUBROUTINE
C      IS TO BE INCORPORATED INTO A PROGRAM TO DETERMINE
C      THE [illegible] OF THE [illegible] FROM THE O/C
C      [illegible]
C
C
        SUBROUTINE EIGE(N,DD,DIP,T,P,Z)
         REAL R(6),E(9),DUB(1000)
       DIMENSION EE(3,3)
       [illegible] DD(10),DIP(10),[illegible]/00/
       EQUIVALENCE (E,EE)
       REAL X(10),Y(10),Z(10)
        INTEGER N
       DO 2 I=1,N
       X(I)=DD(I)
       Y(I)=DIP(I)
2      CONTINUE
       I=0
       CALL DC(X,Y,Z,N)
        DO 20 I=1,6
20      R(I)=0
       DO 30 I=1,N
       A=X(I)
       B=Y(I)
       C=Z(I)
        R(1)=R(1)+A*A
        R(2)=R(2)+A*B
        R(3)=R(3)+B*B
        R(4)=R(4)+A*C
        R(5)=R(5)+B*C
        R(6)=R(6)+C*C
30      CONTINUE
        CALL EIGEN(R,E,3,0)
        CALL TPD1(E(1),E(2),E(3),E(1),E(2))
        E(3)=F(1)
        T=E(1)
        P=E(2)
        Z=E(3)
        RETURN
        END
       SUBROUTINE DC(U1,U2,U3,N)
       REAL U1(N),U2(N),U3(N)
       CALL DGRD(U1,N)
       CALL DGRD(U2,N)
       CALL DDTP(U1,U2,N)
       CALL TPDC(U1,U2,U3,N)
       RETURN
       END
       SUBROUTINE DGRD(A,N)
C   CONVERT TO RADIANS
      REAL A(N)
      REAL PI/3.14159265/,TWOPI/6.2831853/,HALFPI/1.57079633/
      DO 100 I=1,N
100   A(I)=A(I)*1.745329252E-2
      RETURN
      END
      SUBROUTINE DDTP(A,B,N)
C   CONVERT DD AND DIP (RADIANS) TO TREND AND PLUNGE (RADIANS)
      REAL A(N),B(N)
      REAL  PI/3.14159265/,TWOPI/6.2831853/,HALFPI/1.57079633/
      DO 100 I=1,N
      C=A(I)+PI
      IF(C .GT. TWOPI)C=C-TWOPI
      A(I)=C
100   B(I)=HALFPI-B(I)
      RETURN
      END
      SUBROUTINE TPDC(A,B,G,N)
C   TO CONVERT TREND AND PLUNGE RADIANS TO DIRECTION COSINES
      REAL A(N),B(N),G(N)
      REAL PI/3.14159265/,TWOPI/6.2831853/,HALFPI/1.57079633/
      DO 100 I=1,N
      TR=A(I)
      PL=B(I)
      COSP=COS(PL)
      A(I)=COS(TR)*COSP
      B(I)=SIN(TR)*COSP
100   G(I)=SIN(PL)
      RETURN
      END
```

(b) Program STEREO

PURPOSE: To Extract the orientation data from an AR-File and place them in another file, -data, which is then operated on by FINPUT, PLOT and EIGEN.

```
C***** USED TO CONVERT 'AR-FILE' TYPE DATA INTO A FORMAT
C       AMENABLE TO THE ANALIZING PROGRAMS.
        INTEGER DD,SLASH/'/'/,DI
        INTEGER LINE(40)
        INTEGER FM
        READ(5,12)(LINE(I),I=1,40)
        WRITE(6,12)(LINE(I),I=2,40)
        WRITE(6,13)
        DO 1 K=1,500
        READ(5,10,END=9)FM,DD,DI
        IF(FM .EQ. SLASH)  GO TO 9
        IF(DD .NE. 0)GO TO 2
        IF(DI .EQ. 0)  GO TO 1
2       WRITE(6,11)DD,DI
1       CONTINUE
10      FORMAT(A1,16X,2(I3))
11      FORMAT(2(I3,1X))
12      FORMAT(40A1)
 13     FORMAT('TYPE=2')
14      FORMAT('END')
9       WRITE(6,14)
        STOP
        END
```

(c) Procedure for Testing Cylindricity

Data from the East Pit are used below to illustrate the procedures followed in establishing domains within which folding can be considered cylindrical (see p. 25). The chi-square statistic with which to test the cylindricity of a potential domain,

$$K\lambda_3 > \chi^2_{p-2}(\alpha)$$

requires (1) the value of λ_3 calculated using original orientations of bedding collected in the field and stored in columns 46-52 of the AR-file for the East Pit and (2) the pooled estimate K of the concentration parameters stored in columns 32-41. In the case of the East Pit these values were found to be 0.8563 and 65.72, yielding a value for the statistic of 56.26. The critical value of χ^2 with $\alpha=0.05$ is 66.34. Thus the null hypothesis of cylindricity associated with the χ^2 test could not be rejected; i.e. this test suggests that folding within the entire East Pit can be considered cylindrical.

The F statistic,

$$(p-4)(\lambda_3 - \lambda_{3a} - \lambda_{3b})/2(\lambda_{3a}+\lambda_{3b}) > F_{2,p-4}(\alpha)$$

requires the running of EIGEN or CYLTEST using the mean orientations from both the whole and both halves of the East Pit. In the East Pit the resultant value was 22.07 while the F-critical value is 3.20 where $\alpha=0.05$ which leads to the null hypothesis of cylindricity being rejected; i.e. this test suggests that folding within the East Pit can not be considered cylindrical.

An examination of the fold axis orientations and eigenvalue relationships (see computer printout below) showed that the twc halves of the East Pit, EPN and EPS, contain well defined fold axis orientations of 125/30 and 128/14, respectively, with standard scattering angles of about 5.5°. The strong rejection of the F-test along with

```
                         EP
                          50 POINTS
                               EIGENVECTOR          EIGENVALUE      EIGENVALUE/N
                              TREND  PLUNGE

                              234.3    38.1          27.8125         0.556251
                                9.3    42.1          21.3525         0.427049

                              123.5    24.4           0.8347         0.016693
EPN                                                EPS
  30 POINTS                                          20 POINTS

     EIGENVECTOR       EIGENVALUE     EIGENVALUE/N        EIGENVECTOR       EIGENVALUE      EIGENVALUE/N
    TREND  PLUNGE                                        TREND  PLUNGE

      9.4    36.7        16.3911       0.546368          230.6    42.3       14.6371         0.731854
    242.7    38.7        13.3497       0.444989           23.8    44.4        5.1880         0.259398
    125.0    30.2         0.2592       0.008639          127.7    13.8        0.1749         0.008745
EPNW                                               EPNE
  13 POINTS                                          17 POINTS

     EIGENVECTOR       EIGENVALUE     EIGENVALUE/N        EIGENVECTOR       EIGENVALUE      EIGENVALUE/N
    TREND  PLUNGE                                        TREND  PLUNGE

     14.6    26.3         8.7023       0.669407          275.9    57.2        9.4163         0.553901
    253.0    46.6         4.2213       0.324718           29.9    14.6        7.4411         0.437715
    122.4    31.6         0.0763       0.005873          128.1    20.6        0.1425         0.008383
EPSW                                               EPSE
  13 POINTS                                           6 POINTS

     EIGENVECTOR       EIGENVALUE     EIGENVALUE/N        EIGENVECTOR       EIGENVALUE      EIGENVALUE/N
    TREND  PLUNGE                                        TREND  PLUNGE

    230.8    43.7        10.4127       0.800978          236.4    51.2        3.9822          0.663699
     22.8    43.2         2.4473       0.188253           30.4    35.8        1.9881          0.331350
    126.8    14.5         0.1400       0.010767          129.9    12.9        0.0297          0.004948
```

the 17° angular difference in fold axis orientation led to the rejection of cylindricity in the area as a whole.

With the rejection of the East Pit as a domain it became neccesary to test whether or not the two halves could be considered domains in which folding was cylindrical. The above procedures were applied to those values given below. Neither null hypothesis could be rejected and thus folding was considered cylindrical in both areas.

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(d) Run Commands, Sample Input and Output for the Program SECT5 available in the Deptment of Geology

RUN SEQUENCE

```
#1 [illegible]
#15:23:42
 #PRINT# ASSIGNED RECEIPT NUMBER [illegible]
       1.
    123.     30.      0.      0.     9.    125.      30.
 #PRINT#0
 #PRINT# 03C641 RELEASED, 5 PAGES
#15:24:30
#[illegible] file  B
#15:26:10
 FILE  B
 LENGTH  24.0 IN.  APPROX TIME [illegible] COST $  0.52
 DO YOU STILL WANT THIS PLOT OUTPUT [illegible]
 Y
  B QUEUED TO PLOT0002
 [illegible] ISSUED
#15:2[illegible] 0
```

Input

```
 [illegible] STUDY ([illegible])
INPUT DATA:
 STA ID    X    Y    Z      DATA
   1 2    47  -66    4   50 71
   2 2    26  -65   16   45 74
   3 2     5  -41    4   5. 6.
   4 2   -21  -22    4   45 75
   5 2   -42   -4   13   44 83
   6 2   -67   17   23   40 66
   7 2   -86   29   35   44 73
   8 2   -64   72   22  120 53
   9 2   -25   61   15  145 64
  10 1    13   58   14  1.. 34
  11 1     7   81   27  108 47
  12 2     2   93   36  106 32

  51 5   402 -342  -77   37 60
  52 3   301 -437  -30  103 46
  53 4   347 -546  -42  154 35
  54 4   406 -505  -71  155 30
  55 5   348 -564  -69
  56 3   272 -209  -56
  57 3   357 -365  -92
```

Output

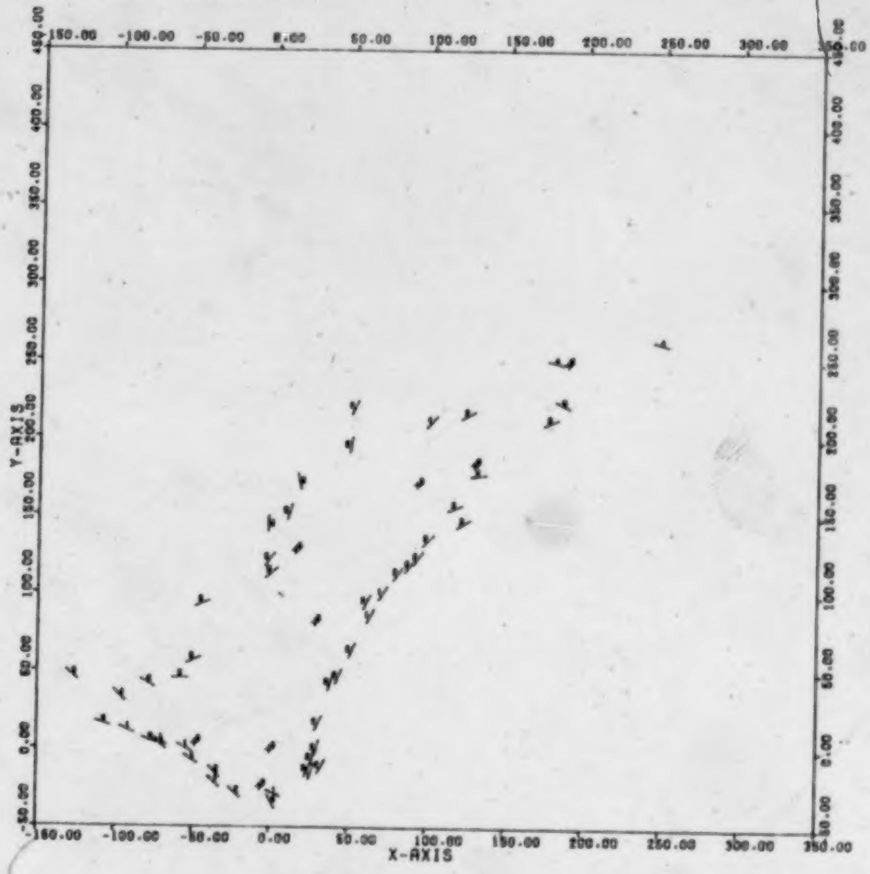
```
#STA        X          Y      PITCH    ID        L          M          N
   1      43.5       47.4     113.4     2   -0.4043     0.9133    -0.0491
   2      38.3       43.1     106.8     2   -0.3222     0.9467    -0.0067
   3      30.7       17.3     116.6     2   -0.4466     0.8928    -0.0572
   4      30.1        1.2     104.5     2   -0.2505     0.9667    -0.0522
   5      27.4       -4.8     100.6     2   -0.1832     0.9803    -0.0735
   6      24.5      -12.4     111.6     2   -0.3648     0.9237     0.1173
   7      26.7      -14.0     108.2     2   -0.3115     0.9492     0.0453
   8     -22.3      -27.6      41.1     2   -0.7502    -0.6542    -0.0958
   9     -35.6      -18.7      45.5     2   -0.6972    -0.7092     0.1045
  10     -55.0        0.8      27.5     1   -0.8783    -0.4581     0.1367
  11     -70.4        3.0      40.7     1   -0.7566    -0.6516     0.0535
  12     -77.3        5.3      20.4     2   -0.9344    -0.3477     0.0777

  51      49.6      196.0      99.7     5   -0.1676     0.9842     0.0571
  52     185.3      222.6      25.7     3   -0.8839    -0.4263    -0.1926
  53     248.2      202.3      16.2     4   -0.9602    -0.2781    -0.0249
  54     186.8      249.6      14.5     4   -0.9665    -0.2500     0.0580
  55     180.7      249.2      61.9     5    0.0000     0.0000    -0.0000
  56      15.2      124.0      61.9     3    0.0000     0.0000    -0.0000
  57      92.6      170.6      61.9     3    0.0000     0.0000    -0.0000
```

POOR COPY

Profile

ORIENTATION OF FOLD AXIS IS [illegible]
COORDINATES OF PROFILE ORIGIN ARE 0.0 0.0 0.0
PROFILE LOOKING IN DIRECTION [illegible]



MPEP MESOSCOPIC STUDY (ROTATED)

POOR COPY

(e) Run Commands, Sample Input and Resulting Output for the Program DOMROT available in the Department of Geology

```
$r hikc:domrot 1=pep 2=*print* 5=*source* 7=*print* 9=*print*
$15:11:06
 *PRINT* ASSIGNED RECEIPT NUMBER 330637
     120.      14.     125.    -162.      5.     125.      30.

 DOMAIN ROTATION PROGRAM
 FOLD AXIS IS     120.0    14.0
 TO BE ROTATED TO  125.0     5.0
 ABOUT THE POINT   125.0  -162.0
  MPEP MESOSCOPIC STUDY (SOUTH)
 125555222222334553445333
 *PRINT* 830637 RELEASED, 3 PAGES
$15:15:32 .161 RC=0
```

INPUT

```
 MPEP MESOSCOPIC STUDY (SOUTH)
INPUT DATA:
 STA  ID    X     Y      Z      DATA
   1  1   133  -183    -2   45  59
   2  2   162  -217     6   51  56
   3  5   226  -162     3   51  56
   4  5   266  -191    14  215  58
   5  5   299  -234    10   66  76
   6  5   358  -285    11  213  78
   7  2   281  -355     0   64  26
   8  2   258  -344    -4   37  31
   9  2   237  -299    -5   36  44
  10  2   205  -266    -5   45  56
  11  2   183  -243    -3   52  53
  12  2   319  -403     7   92  13
  13  3   292  -439    43   77  31
  14  3   409  -463    20   56  30
  15  4   416  -438    18   51  50
  16  5   429  -386    31   53  69
  17  5   400  -360    16   37  81
  18  3   285  -443    56  174  35
  19  4   326  -553    73  173  21
  20  5   383  -523    52
  21  4   392  -520    51  161  17
  22  3   275  -222    -9
  23  3   357  -383    -5
  24  3   375  -443    -3
```

OUTPUT

```
 MPEP MESOSCOPIC STUDY (SOUTH)
ROTATED DATA:
  STA  ID      X     Y      Z  DATA
    1  1     134  -141     -7    54  62
    2  2     163  -213    -17    58  60
    3  5     225  -156    -17    58  60
    4  5     267  -194    -20   216  59
    5  5     299  -223    -39    67  76
    6  5     356  -270    -59   207  81
    7  2     283  -341    -67    84  35
    8  2     254  -331    -64    60  33
    9  2     237  -288    -52    52  45
   10  2     205  -258    -40    53  58
   11  2     174  -237    -29    60  57
   12  2     323  -387    -77   111  27
   13  3     305  -431    -43    90  42
   14  3     415  -443    -96    76  37
   15  4     426  -418    -93    61  54
   16  5     435  -368    -73    56  73
   17  5     402  -342    -77    37  90
   18  3     301  -437    -30   160  48
   19  4     347  -546    -42   154  35
   21  4     406  -505    -71   155  30
   20  5     398  -509    -69
   22  3     272  -209    -50
   23  3     357  -362    -92
   24  3     376  -421   -105
```

POOR COPY

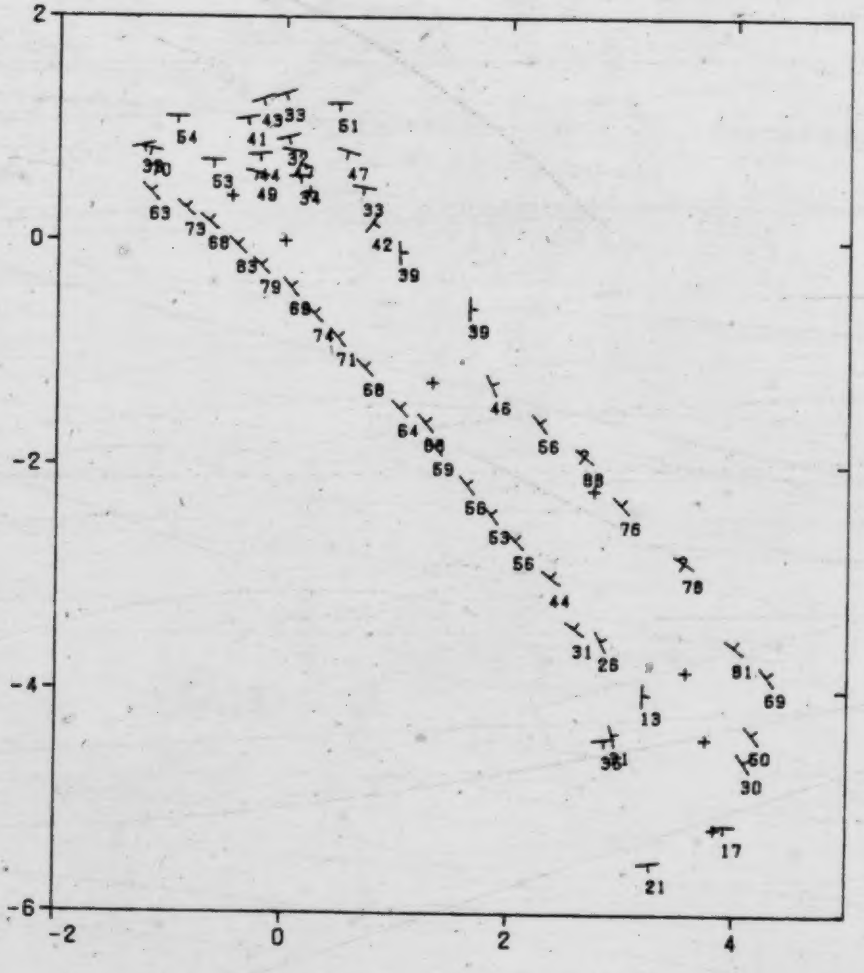
(f) Mapping Subroutines BOUND, DRAW and MAP

```
C********SUBROUTINES TO PLOT ORIENTATION  SYMBOLS ON MAPS ********
C
C        THIS FILE CONTAINS THREE SUBROUTINES REQUIRED IN THE PLOTTING
C         OF MAPS.  MAP READS INPUT DATA AND CALLS SUBROUTINE DRAW TO
C          CONSTRUCT THE ORIENTATION SYMBOLS.  DRAW CONSTRUCTS THE
C           ORIENTATION SYMBOLS WHILE BOUND IS USED TO PUT A BOUNDARY
C            AROUND THE ENTIRE MAP.
C
      SUBROUTINE BOUND(A,B,C,D,E,F)
C******* DESIGNED TO DRAW A BOUNDARY AROUND A MAP
C         LABELS BEING ON BASE AND LEFT HAND AXIS.
C  A=XLENGTH
C  B=YLENGTH
C  C=X LABEL
C  D=Y LABEL
C  E=UNIT INCREMENT PER VIRTUAL UNIT
C  F=TIC SPACING
      G=A+1.
      H=B+1.
      CALL AX2EP(F,1,-1)
      CALL AXIS2(1.,1.,' ',-1,A,0.,C,E,F)
      CALL AXIS2(1.,1.,' ',1,B,90.,D,E,-F)
      CALL AXIS2(1.,H,' ',-1,-A,0.,C,E,F)
      CALL AXIS2(G,1.,' ',1,-B,90.,D,E,F)
      RETURN
      END
C***************SUBROUTINE DRAW ********************
      SUBROUTINE DRAW(X,Y,N,HT,DD,DI)
      INTEGER N
      REAL DD,DI,DDD,Z,W,V
      REAL X,Y,S,HT,K,KK,P,Q
      IF(N .EQ. 0)GO TO 30
C********CHECK IF BEDS OVERTURNED, IF SO ADD 180 TO DIP-DIRECTION
       IF(DI .LE. 90.0)  GO TO 15
       DDD=DD+180.
       IF(DDD .LE. 360.)  GO TO 3
       DDD=DDD-360.
       W=ABS(DDD-450.)
       GO TO 6
3      W=ABS(DDD-450.)
6      G=W+90.0
       H=W+270.
       R=HT/4.
      DD=DDD
C********CONVERT DEGREES TO RADIANS
15     Z=DD*1.745329E-2
      U=(DD+180.)*1.745329E-2
       V=(DD+90.0)*1.745329E-2
       K=(DD-90.0)*1.745329E-2
      IF(DI .LE. 90.0)  GO TO 20
C******* COORDINATE CALCS. FOR  OVERTURNED CIRCLE SYMBOL AND ITS PLOTTING
      X1=X+SIN(U)*(HT*.33)
      Y1=Y+COS(U)*(HT*.33)
      X2=X+SIN(V)*(HT*.5)
      Y2=Y+COS(V)*(HT*.5)
      X3=X2+SIN(U)*(HT*.33)
      Y3=Y2+COS(U)*(HT*.33)
      CALL PLOT(X,Y,3)
      CALL PLOT(X1,Y1,2)
      CALL CIRCLE(X1,Y1,G,H,R,R,0.0)
      CALL PLOT(X3,Y3,3)
      CALL PLOT(X2,Y2,2)
      DI=180.-DI
C**********DETERMINE COORDINATES FOR SYMBOL
20     E=X+SIN(Z)*(HT*.66)
       F=Y+COS(Z)*(HT*.66)
       A=X+SIN(V)*HT
       B=Y+COS(V)*HT
       C=X+SIN(K)*HT
       D=Y+COS(K)*HT
C********PLOT SYMBOL ***********
      CALL PLOT(E,F,3)
      CALL PLOT(X,Y,2)
      CALL PLOT(A,B,3)
      CALL PLOT(C,D,2)
      Q=Y-(2.5*HT)
      CALL NUMBER(X,Q,HT,DI,0.0,-1)
30    RETURN
      END
C*****  READ DATA AND PLOT SYMBOLS *******
      SUBROUTINE MAP(A,B,D,E)
      INTEGER C,BLANK/' '/,X,Y,DD,DI
      N=1
      DO 1 I=1,500
      READ(5,10,END=9)X,Y,DD,DI,C
      IF(C .EQ. BLANK)  GO TO 2
      DI=90-DI+90
      DD=DD+180
      IF(DD .GT. 360)  DD=DD-360
2     XX=(X+A)/D+1.
      YY=(Y+B)/D+1.
      IF(DD .EQ. 0)  GO TO 3
      DDD=DD
      DID=DI
      CALL DRAW(XX,YY,N,E,DDD,DID)
      GO TO 1
3     CALL SYMBOL(XX,YY,E,003,0.0,-1)
1     CONTINUE
10    FORMAT(1X,2(I5),6X,2I3,1X,A1)
9     RETURN
      END
```

POOR COPY

Example of Map Production

```
#cr -file
# FILE '-FILE' HAS BEEN CREATED.
#number
#      1_       call plots
#      2_       call bound(7.,8.,-2.,-6.,1.,2.)
#      3_       call map(-200.,-600.,100.,.1)
#      4_       call plots(0.0,0.0,999)
#      5_       stop
#      6_       end
#      7_#unnumber
#r *forts scards=-file
#15:13:24
 MAIN       NO ERRORS
#15:13:26 .113 RC=0
#r -load#+bankc+*plotlib 5=ep(2,59) 9=-map
#15:19:08
#15:19:10 .145 RC=0
#r *calcompq par=file=-map
#15:19:27
 FILE=-MAP
 LENGTH= 19.5 IN.  APPROX TIME=   64. SECS.  APPROX COST=$  0.37
 DO YOU STILL WANT THIS PLOT QUEUED? (Y OR N)
```



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(g) Run Commands and Sample Output for the Programs STEREO, FINPUT and PLOT available in the Department of Geology

```
#$RUN STEREO 5=DOMAIN1 6=-DATA
#21:30:55
#21:30:57  T=.202  RC=0
#$SOURCE HAKC:FINPUT
#$CR -OD1 TYPE=SEQ SIZE=10P
# FILE '-OD1' HAS BEEN CREATED.
#$CR -OD2 TYPE=SEQ SIZE=10P
# FILE '-OD2' HAS BEEN CREATED.
#$R HAKC:FINPUT(100)+HAKC:ODPROLIB 1=-DATA 5=*MSOURCE* 6=*SINK* 7=-OD1 9=-SCR
#21:31:16
  DOMAIN 1
#21:31:21  T=1.045  RC=0
#$COPY -OD1 -OD2
#$SOURCE HAKC:PLOT
#$R *SOURCE*+HAKC:ODPROLIB 1=-OD2 5=*MSOURCE* 6=*SINK* 9=-SCR
#21:31:33
 TO SKIP TO NEXT DATA SET ENTER A BLANK LINE
 TO TERMINATE ENTER '?'
  DOMAIN 1
   55 POINTS
 ENTER PERCENT SIZE OF COUNTING CIRCLE
 1


  DOMAIN 1
  PERCENT OF  55 POINTS IN  1.0 PERCENT OF AREA OF HEMISPHERE
 EQUAL-AREA PROJECTION: FRACTIONS TRUNCATED
                                 0   0   0   0   0
                         0   0   0   0   0   0   0   0   0
                     0
                                                             0
                 0   0   0   0   0   0   0   0   0   0   0   0   0
              0
                                                                    0
             0   0   0   0   0   0   0   1   3   5   5   1   0   0   0
          0
                                                                        0
         0   0   0   0   0   0   0   1   9  16  16   5   1   0   0   0   0
       0
                                                                           0
     0   0   0   0   0   0   0   0   3  10  16  10   3   1   0   0   0   0   0
     0   0   0   0   0   0   0   1   9   7   7   3   0   0   0   0   0   0   0
   0
                                                                              0
     0   0   0   0   0   3   9  16  10   3   0   0   0   0   0   0   0   0   0
  0
                                                                               0
  0  0   0   0   0   0   7   7   9   1   0   0   0   0   0   0   0   0   0   0 0
  0
                                                                               0
     0   0   0   0   1   5   3   0   0   0   0   0   0   0   0   0   0   0   0
   0
                                                                              0
     0   0   0   1   1   3   1   1   0   0   0   0   0   0   0   0   0   0   0
     0   0   0   1   1   0   0   0   0   0   0   0   0   0   0   0   0   0   0
      0
                                                                          0
         0   0   1   1   0   0   0   0   0   0   0   0   0   0   0   0   0
         0
                                                                       0
             0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
             0
                                                                   0
                 0   0   0   0   0   0   0   0   0   0   0   0   0
                    0
                                                            0
                         0   0   0   0   0   0   0   0   0
                                 0   0   0   0   0
```

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(h) Run Commands and the APL Program THICK Used to Calculate the Thickness of Strata Between Two Outcrops Whose Coordinates and Bedding Orientations are Known

```
      WESTFIT←5297 1771 6618 201 32 THICK ¯5494 3838 6255 187 37
FOLD-AXIS :  231.2  28.4
THICKNESS:   63.7

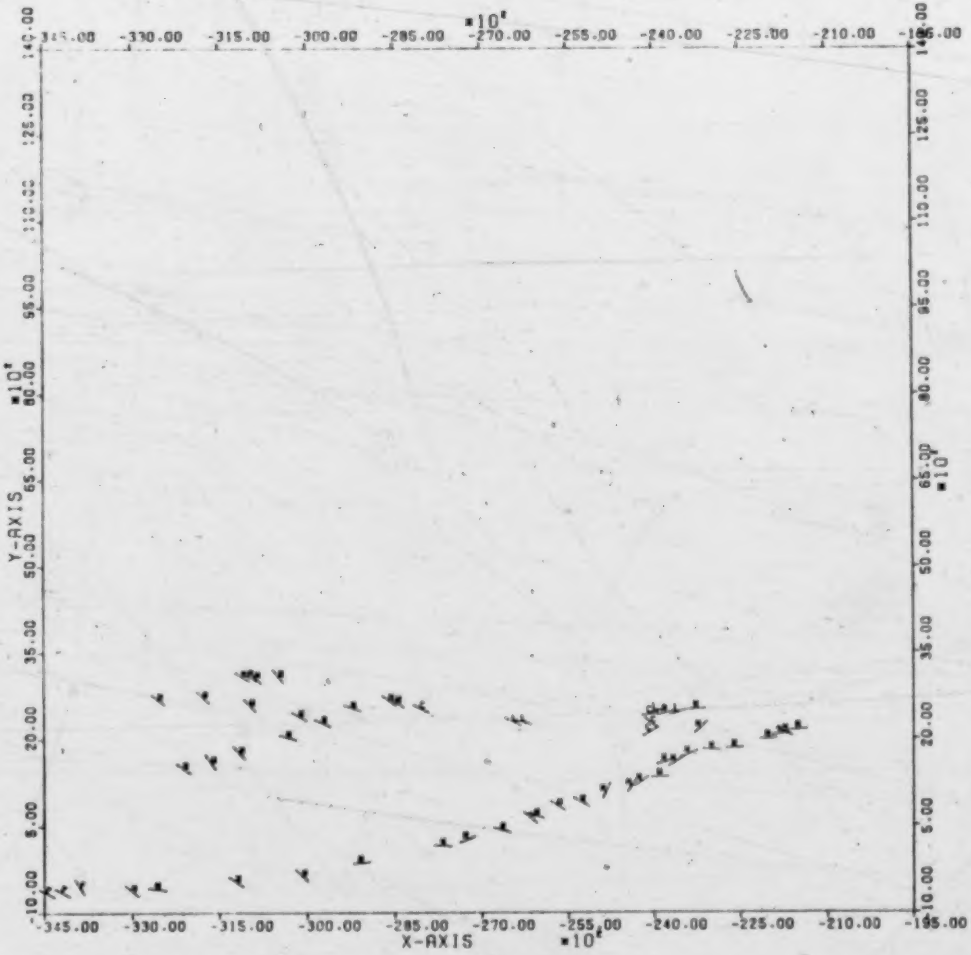
      BRJINONDER←¯21357 ¯5837 5771 105 21 THICK ¯25977 6731 2405 105 21
THICKNESS:  273.8

      ∇THICK[⎕]∇
    ∇ TH←G THICK R;DC;DCT;LM;MN;LMN;TP;RM;W;PIT;MC;RHS;INT;L1;L2;XYZ;NPT
[1]   →((G[4] R[4]) [illegible] R[3]-G[3]))/15
[2]   LM←(¯1 0 2 ↑DCT)⌹ 0 ¯1 ↓DCT←⍉ 2 0 DCOS G[3+⍳2],(R[1]+1E¯7),R[5]
[3]   LMN←LM÷MN←(1++/LM*2)*0.5
[4]   TP←RA×(LMN[2]TRND LMN[1]),¯1○LMN[3]
[5]   RM←3 3 DCOS(TP[1]+90),0,TP[1],(TP[2]-90),TP
[6]   XYZ←RM+.×(R[2]-G[2]),(R[1]-G[1]),-R[3]-G[3]
[7]   W←RM+.×DC
[8]   MC←⍉ 2 2 ⍴(2○NPT),1○NPT←(PI÷2)+PIT+2×PI×0>PIT←¯3○W[1;]÷W[2;]+1E¯7
[9]   RHS←0,MC[2;]+.×XYZ[ 2 1 ]
[10]  INT←RHS⌹MC
[11]  L1←(+/INT*2)*0.5
[12]  TH←L1-L2←(+/(INT-XYZ[ 2 1 ])*2)*0.5
[13]  'FOLD-AXIS :    ',⍕1⍕TP
[14]  →16
[15]  TH←((R[2]-G[2]),(R[1]-G[1]),(-R[3]-G[3]))+.×DC← 2 0 DCOS G[ 4 5 ]
[16]  'THICKNESS:  ',⍕1⍕TH
```

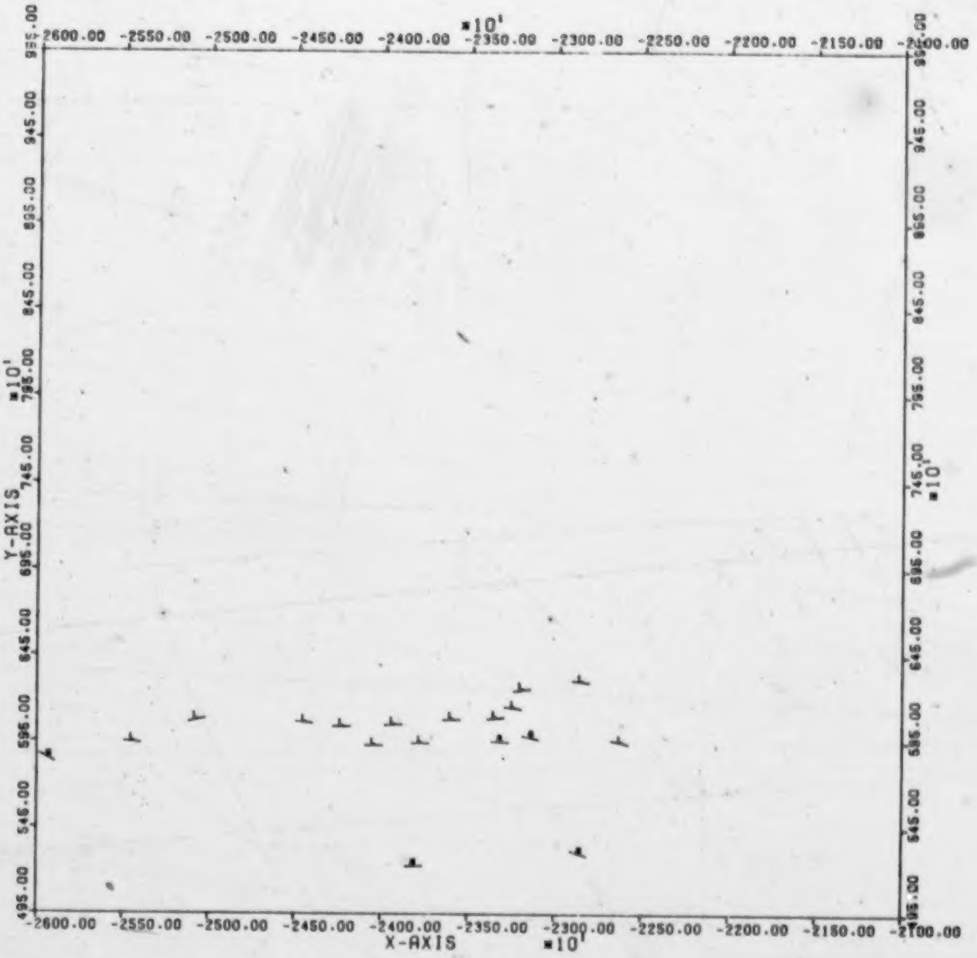
APPENDIX 4

Domain Plots

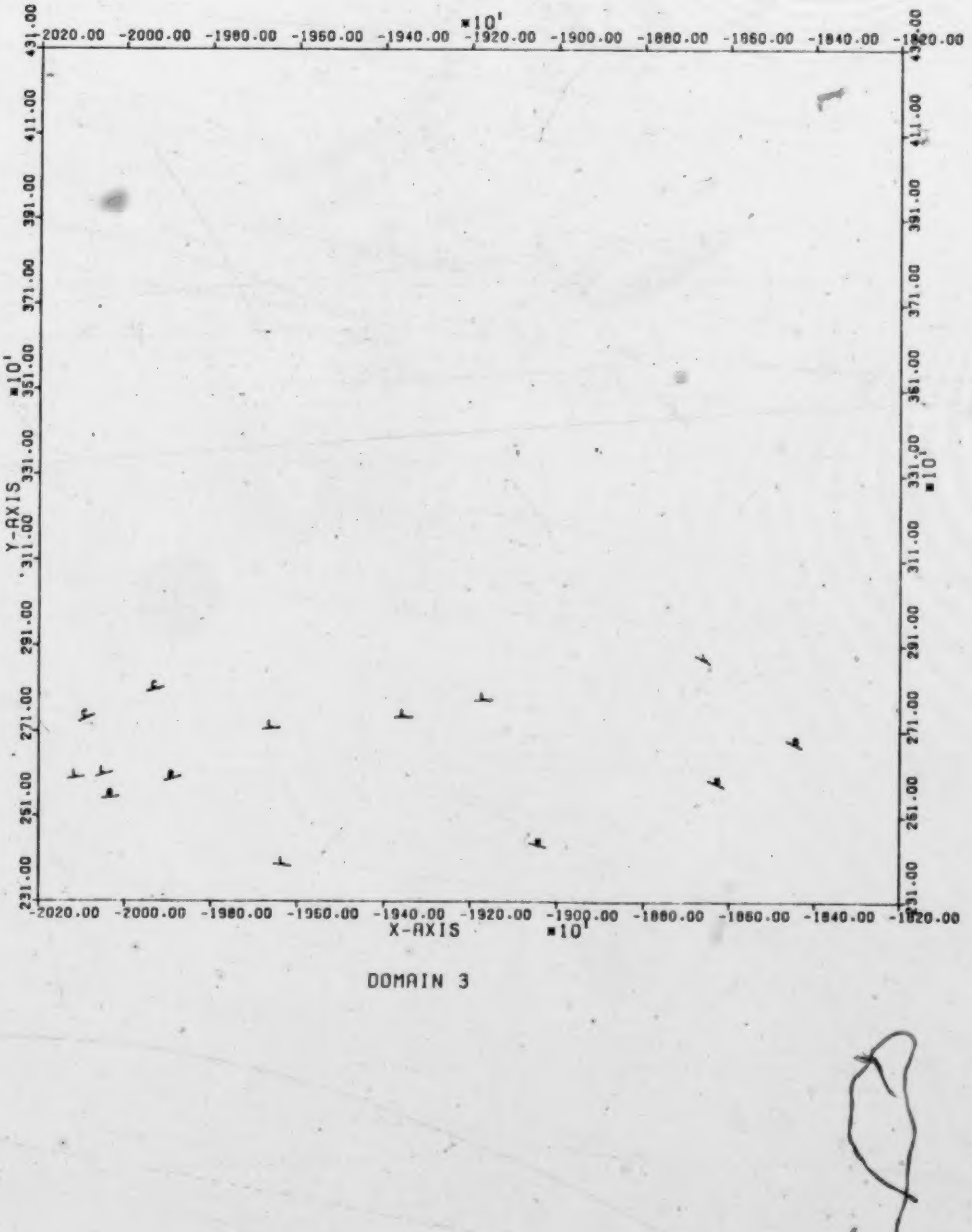
K=Carduim
B=Blackstone
M=Mountain Park
L=Luscar
1=Kennedy Seam
2=Kennedy Seam
C=Cadomin
N=Nikanassin
F=Fernie
P=pre-Jurassic


*10'
-345.00
-330.00
-315.00
-300.00
-285.00
-270.00
-255.00
-240.00
-225.00
-210.00
-195.00
140.00
125.00
110.00
95.00
80.00
65.00
50.00
35.00
20.00
5.00
-10.00
Y-AXIS
*10'
X-AXIS
*10'

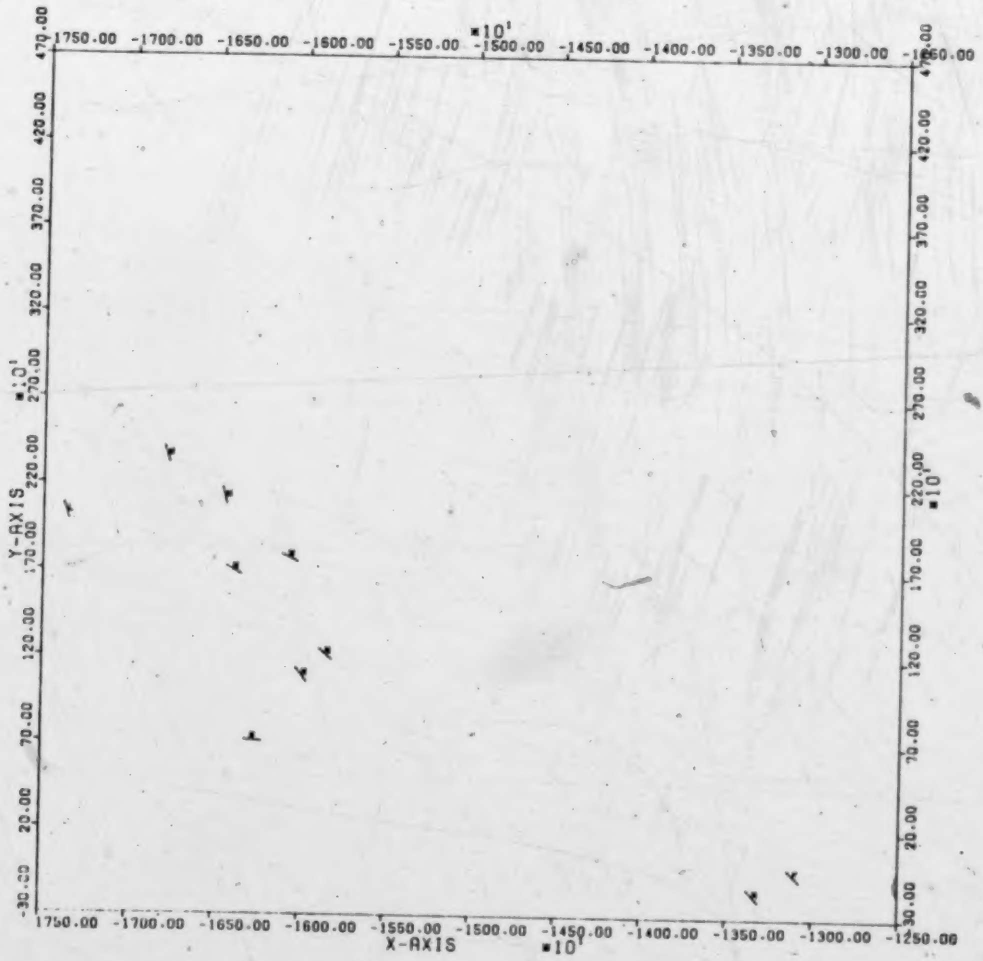
DOMAIN 1


*10¹
-2600.00
-2550.00
-2500.00
-2450.00
-2400.00
-2350.00
-2300.00
-2250.00
-2200.00
-2150.00
-2100.00
995.00
945.00
895.00
845.00
795.00
745.00
695.00
645.00
595.00
545.00
495.00
Y-AXIS
*10¹
X-AXIS
*10¹

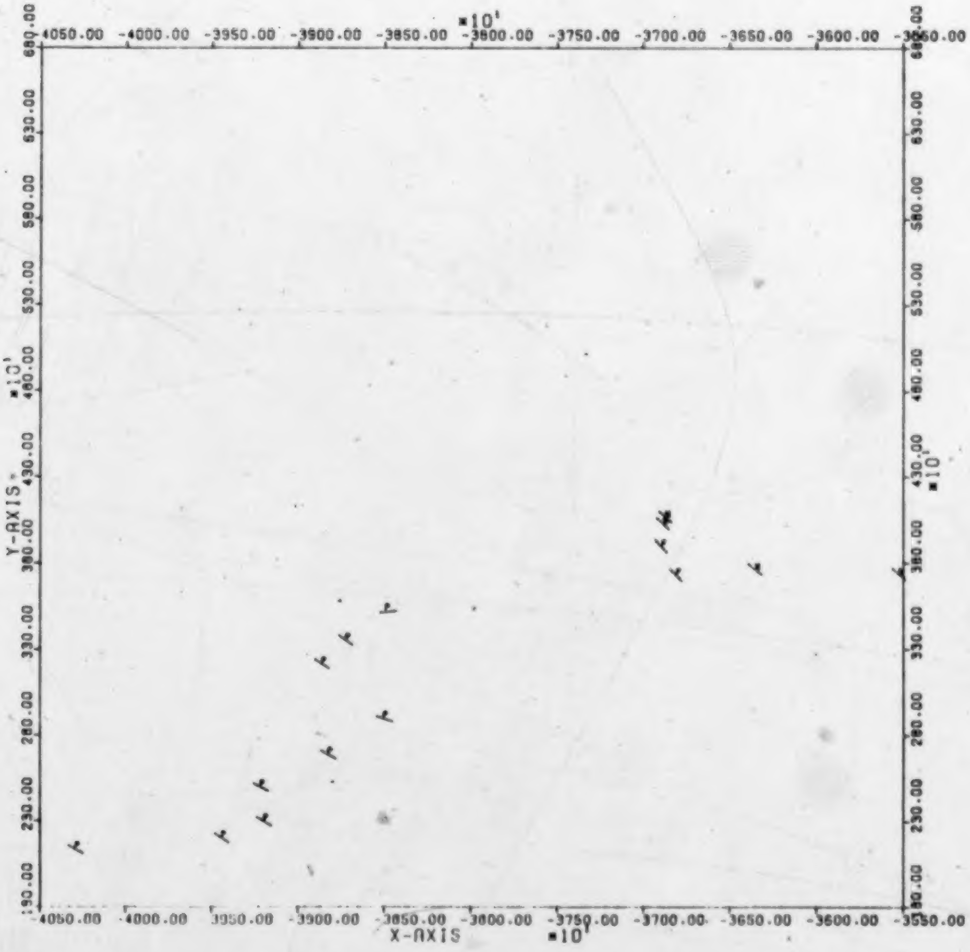
DOMAIN 2


*10'
-2020.00
-2000.00
-1980.00
-1960.00
-1940.00
-1920.00
-1900.00
-1880.00
-1860.00
-1840.00
-1820.00
431.00
411.00
391.00
371.00
351.00
331.00
311.00
291.00
271.00
251.00
231.00
Y-AXIS
*10'
X-AXIS
*10'

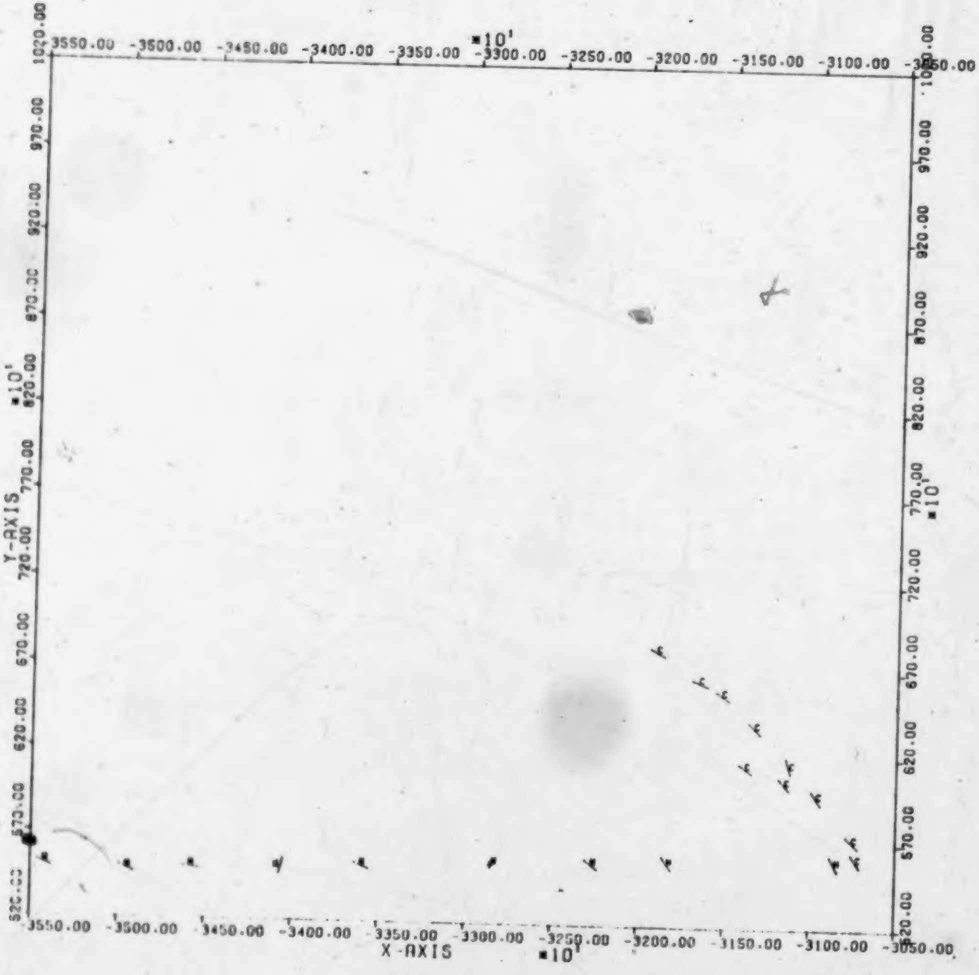
DOMAIN 3


*10¹
-1750.00
-1700.00
-1650.00
-1600.00
-1550.00
-1500.00
-1450.00
-1400.00
-1350.00
-1300.00
-1250.00
Y-AXIS
*10¹
470.00
420.00
370.00
320.00
270.00
220.00
170.00
120.00
70.00
20.00
-30.00
X-AXIS
*10¹

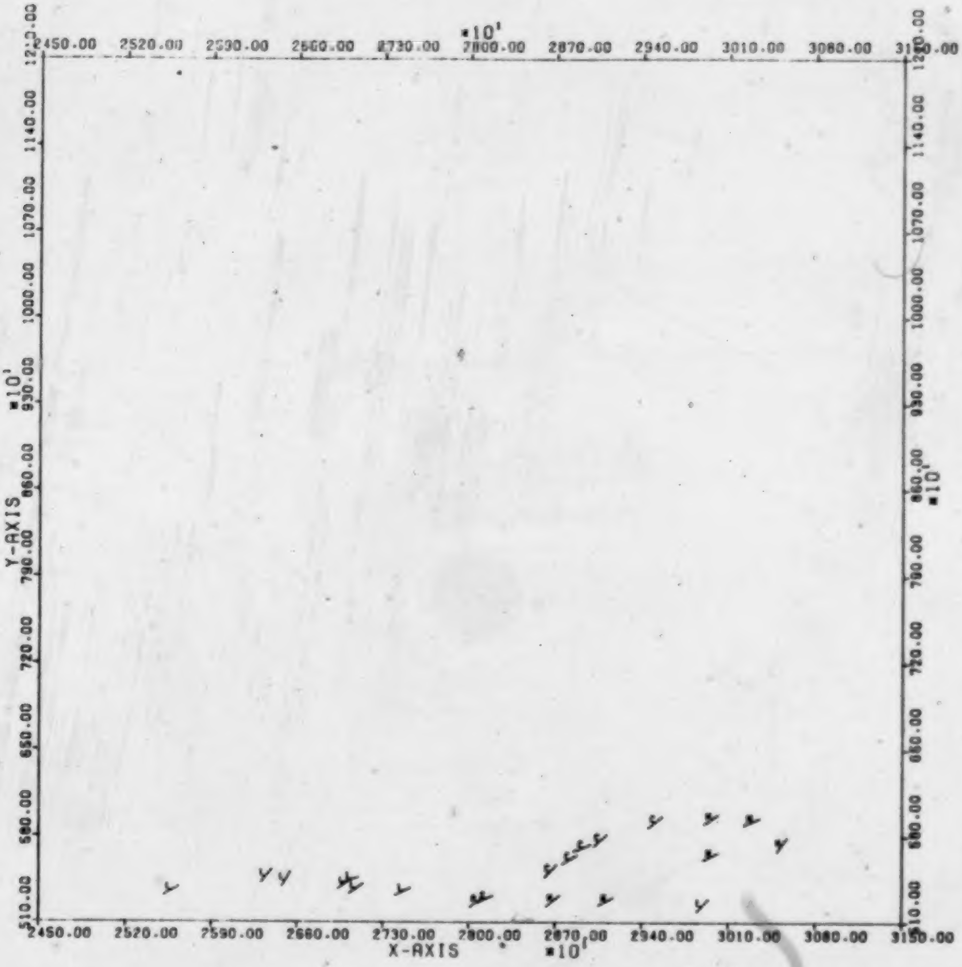
DOMAIN 4


-4050.00
-4000.00
-3950.00
-3900.00
-3850.00
-3800.00
-3750.00
-3700.00
-3650.00
-3600.00
-3550.00
*10¹
X-AXIS
Y-AXIS
190.00
230.00
280.00
330.00
380.00
430.00
480.00
530.00
580.00
630.00
680.00

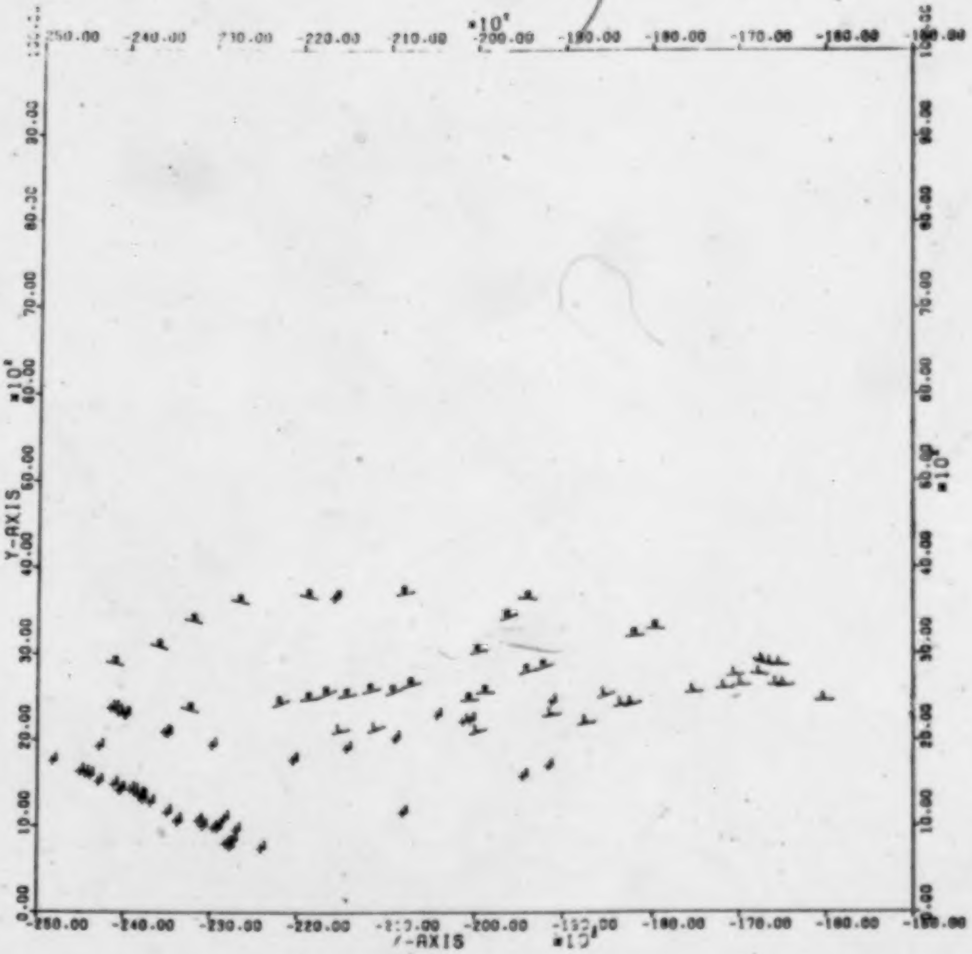
DOMAIN 5


-3550.00
-3500.00
-3450.00
-3400.00
-3350.00
-3300.00
-3250.00
-3200.00
-3150.00
-3100.00
-3050.00
*10¹
X-AXIS
Y-AXIS
520.00
570.00
620.00
670.00
720.00
770.00
820.00
870.00
920.00
970.00
1020.00

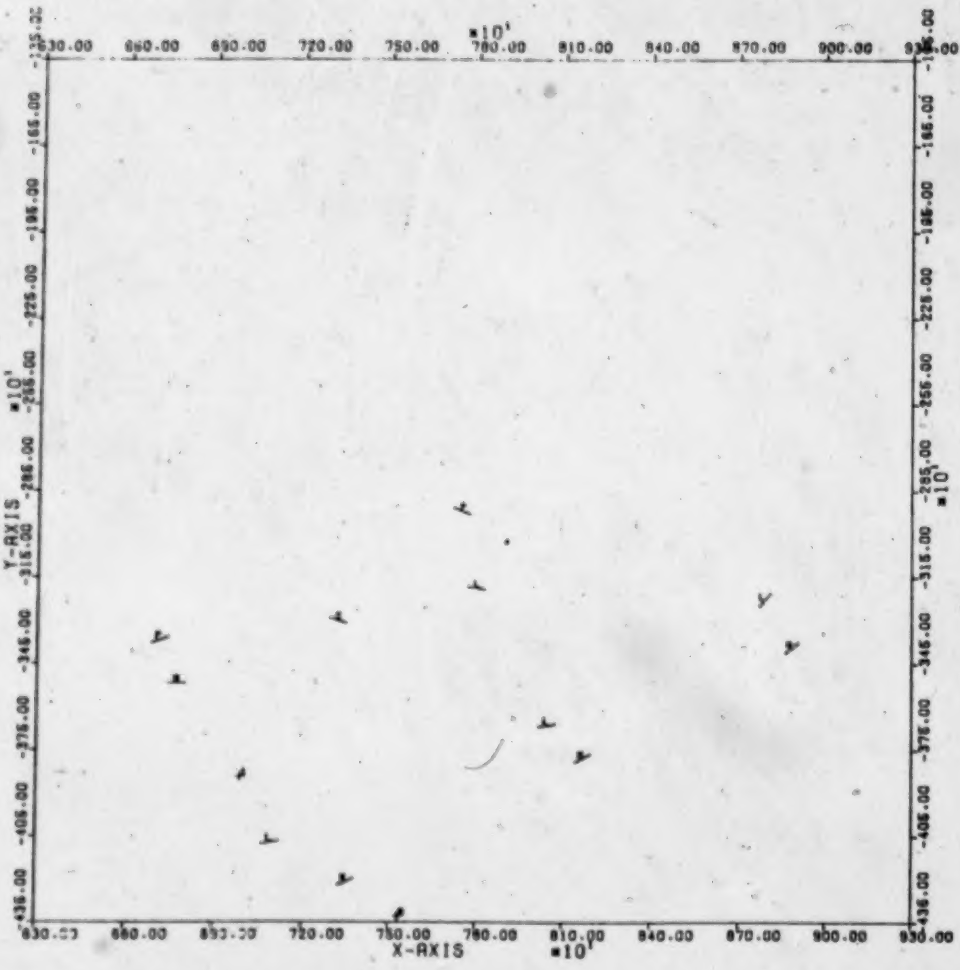
DOMAIN 5(A)


*10'
2450.00
2520.00
2590.00
2660.00
2730.00
2800.00
2870.00
2940.00
3010.00
3080.00
3150.00
Y-AXIS
*10'
510.00
580.00
650.00
720.00
790.00
860.00
930.00
1000.00
1070.00
1140.00
1210.00
X-AXIS
*10'

DOMAIN 6


*10¹
-250.00
-240.00
-230.00
-220.00
-210.00
-200.00
-190.00
-180.00
-170.00
-160.00
-150.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
Y-AXIS
*10¹
X-AXIS
*10¹

DOMAIN 7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840.00
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900.00
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-196.00
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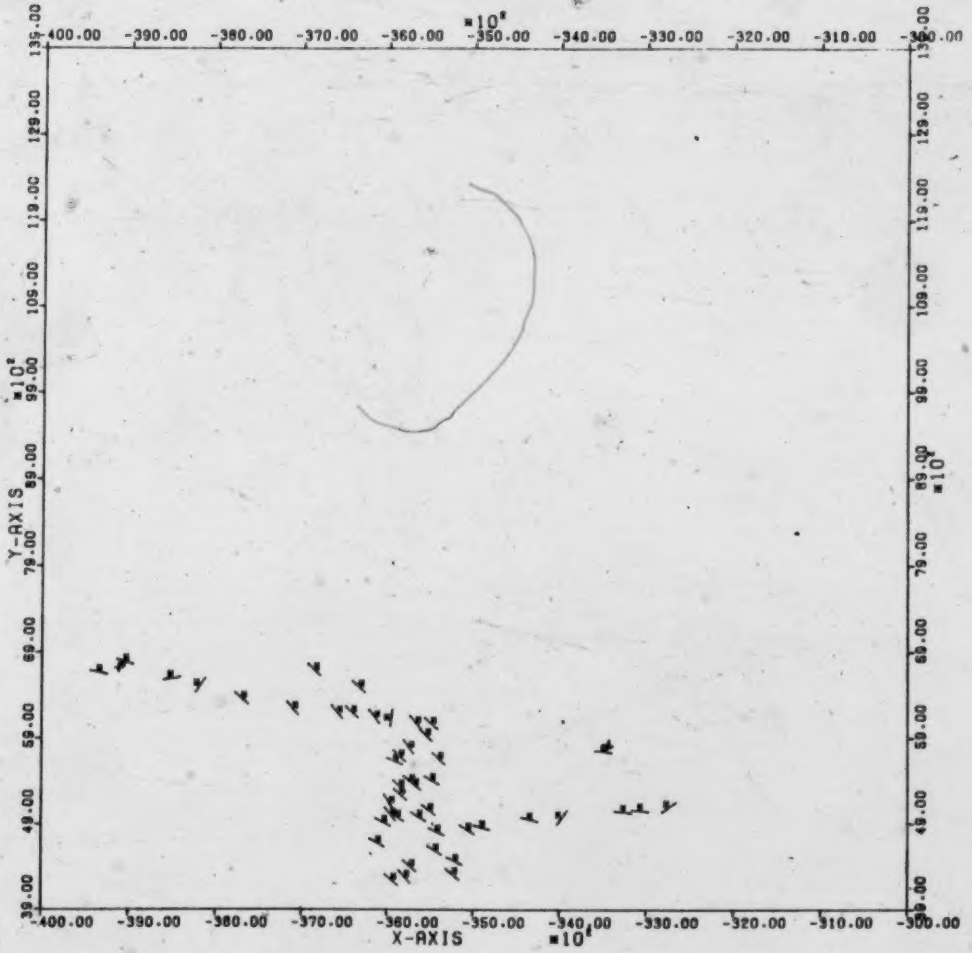
Y-AXIS
X-AXIS
*10¹

DOMAIN 8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59.00
69.00
79.00
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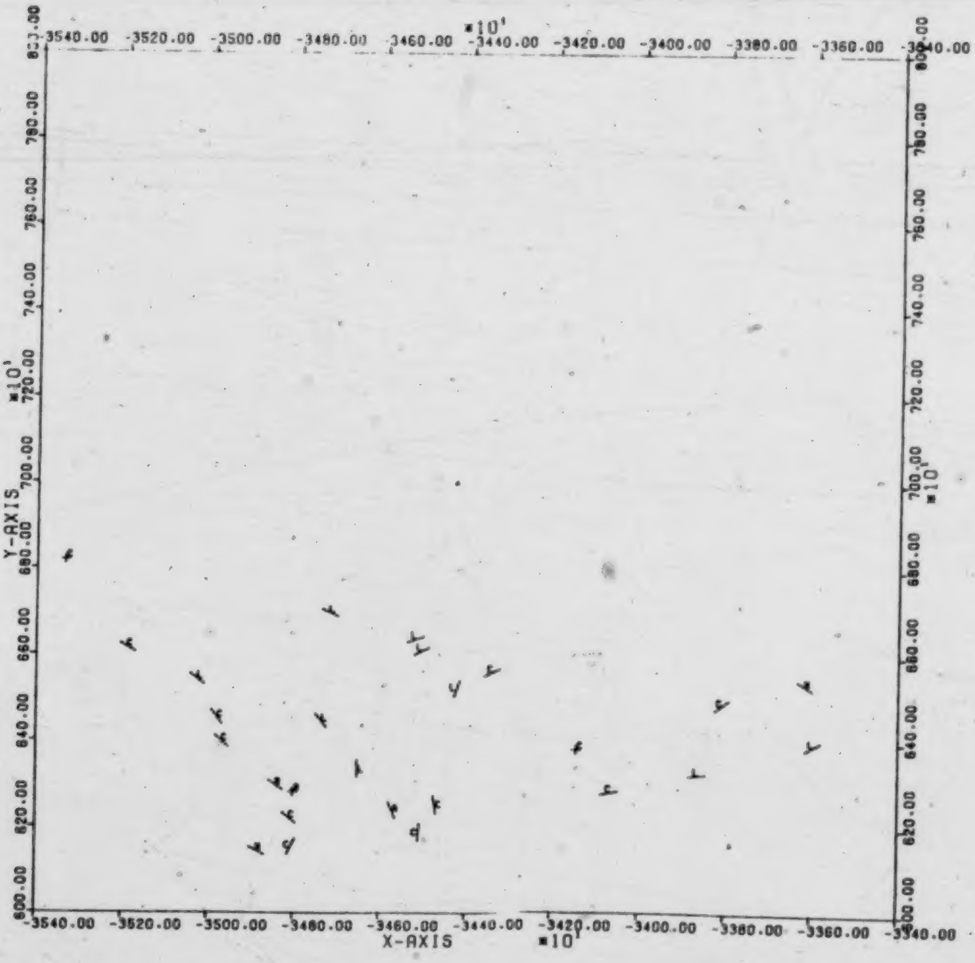
109.00
119.00
129.00
139.00
Y-AXIS
*10²
X-AXIS
*10²

DOMAIN 9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-3380.00
-3360.00
-3340.00
X-AXIS
*10¹
Y-AXIS
*10¹
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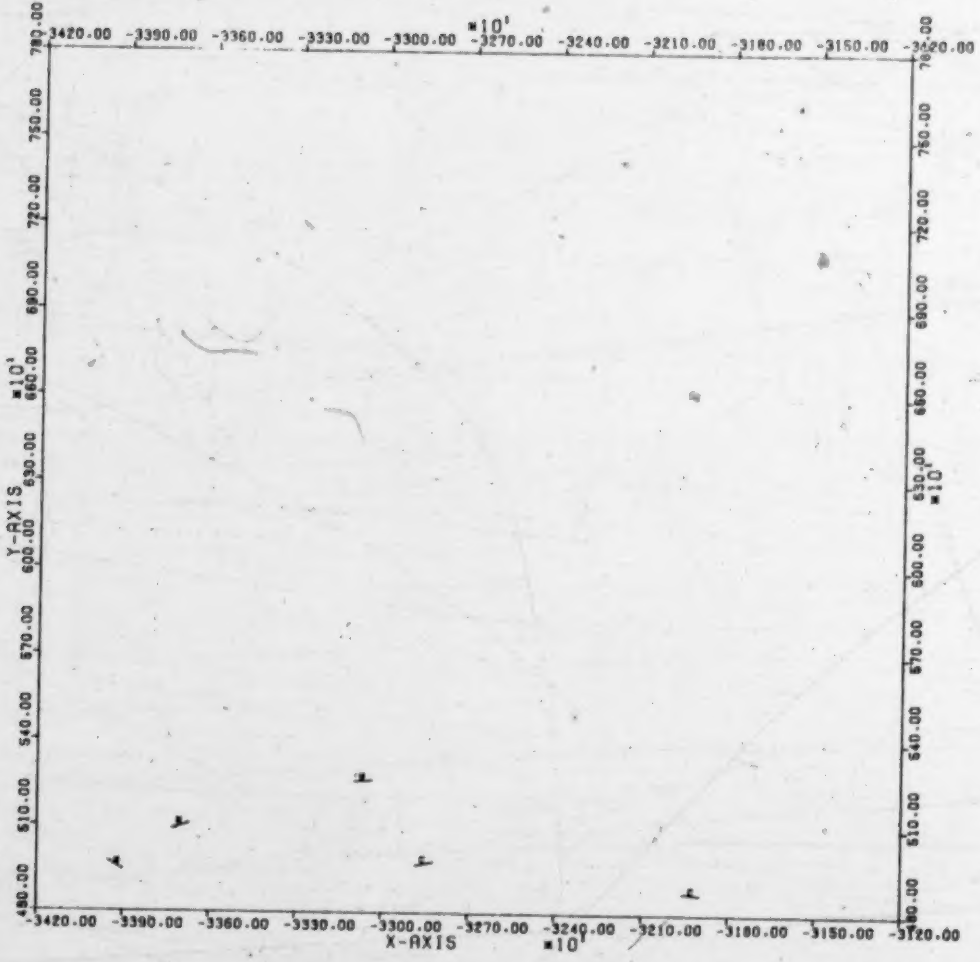
620.00
640.00
660.00
680.00
700.00
720.00
740.00
760.00
780.00
800.00

DOMAIN 10



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-3210.00
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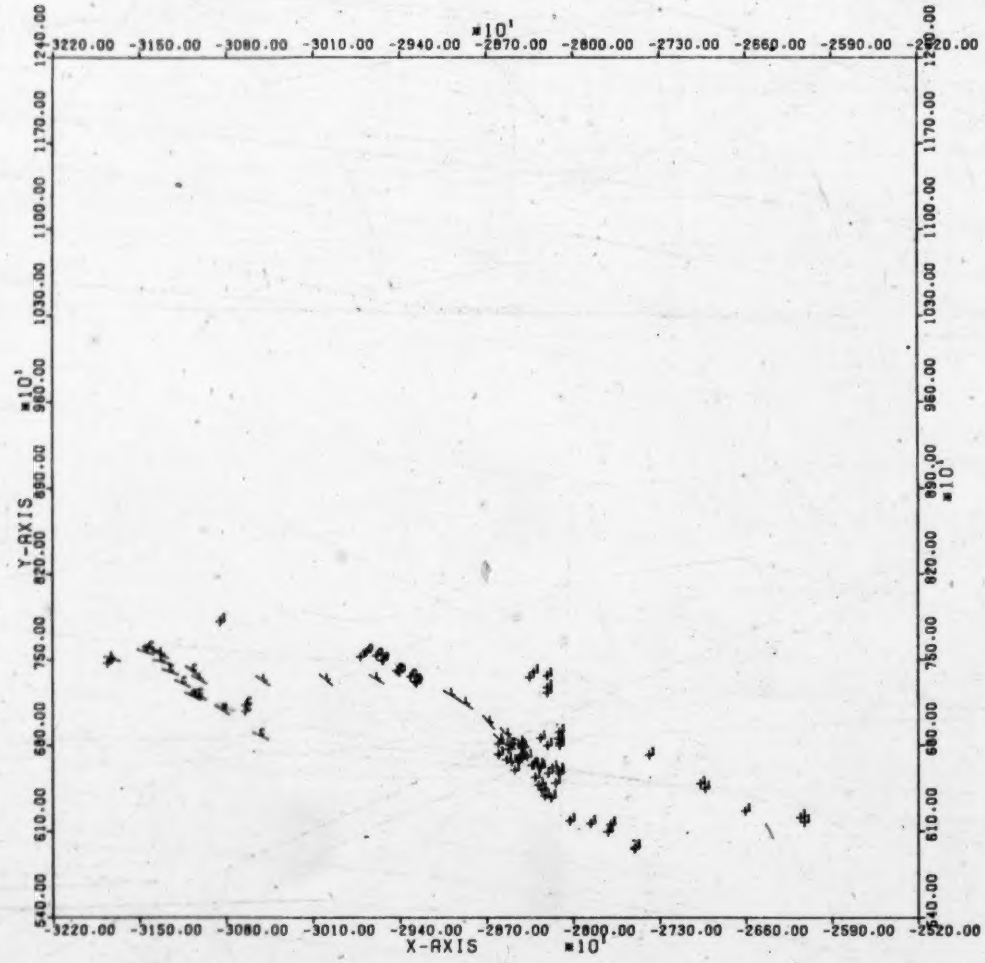
-3120.00
780.00
750.00
720.00
690.00
660.00
630.00
600.00
570.00
540.00
510.00
480.00
Y-AXIS
*10¹
X-AXIS
*10¹

DOMAIN 11.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-2870.00
-2800.00
-2730.00
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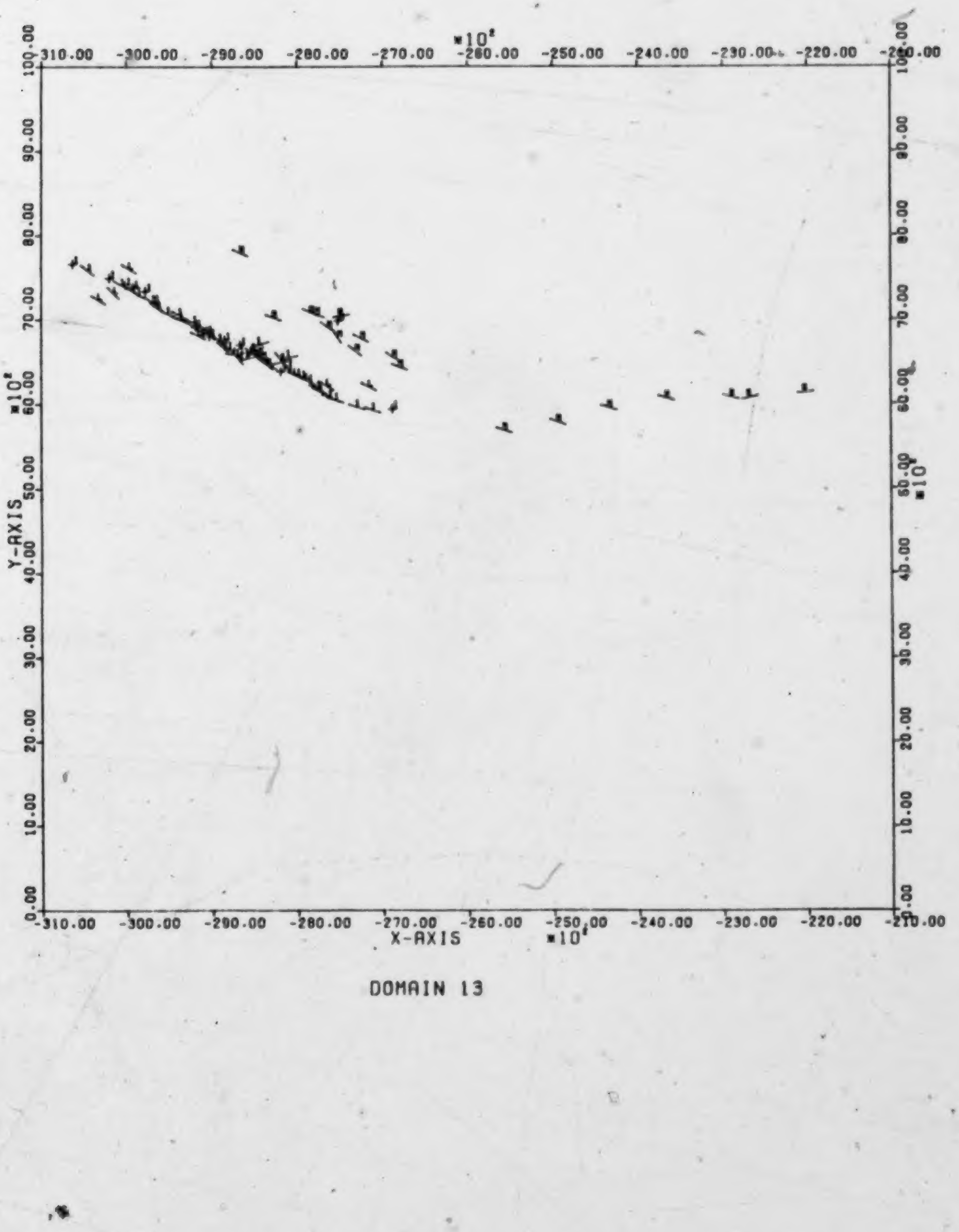
-2590.00
-2520.00
540.00
610.00
680.00
750.00
820.00
890.00
960.00
1030.00
1100.00
1170.00
1240.00
Y-AXIS
*10'
X-AXIS
*10'

DOMAIN 12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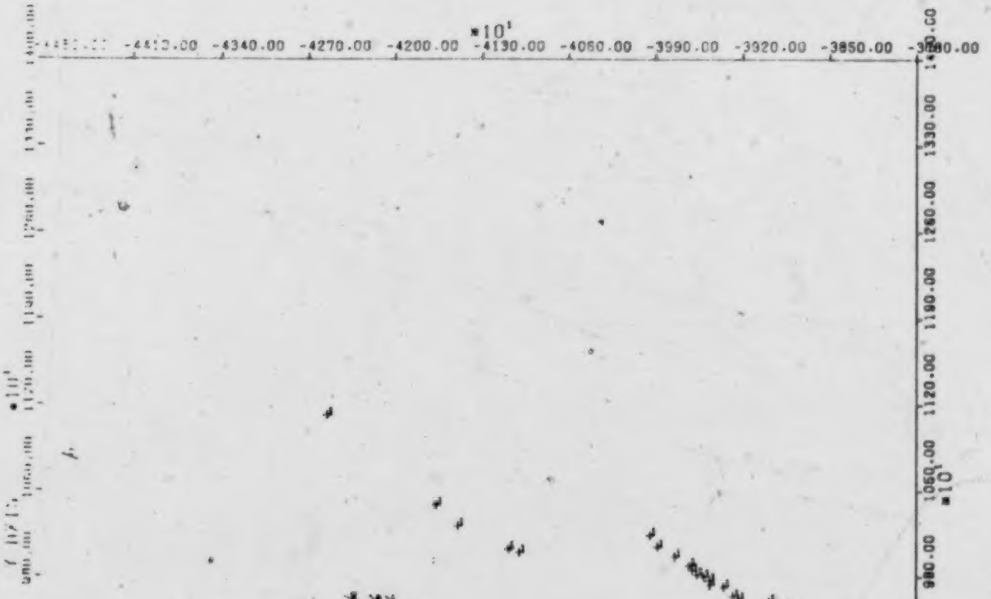
-220.00
-210.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
Y-AXIS
*10²
X-AXIS
*10²

DOMAIN 13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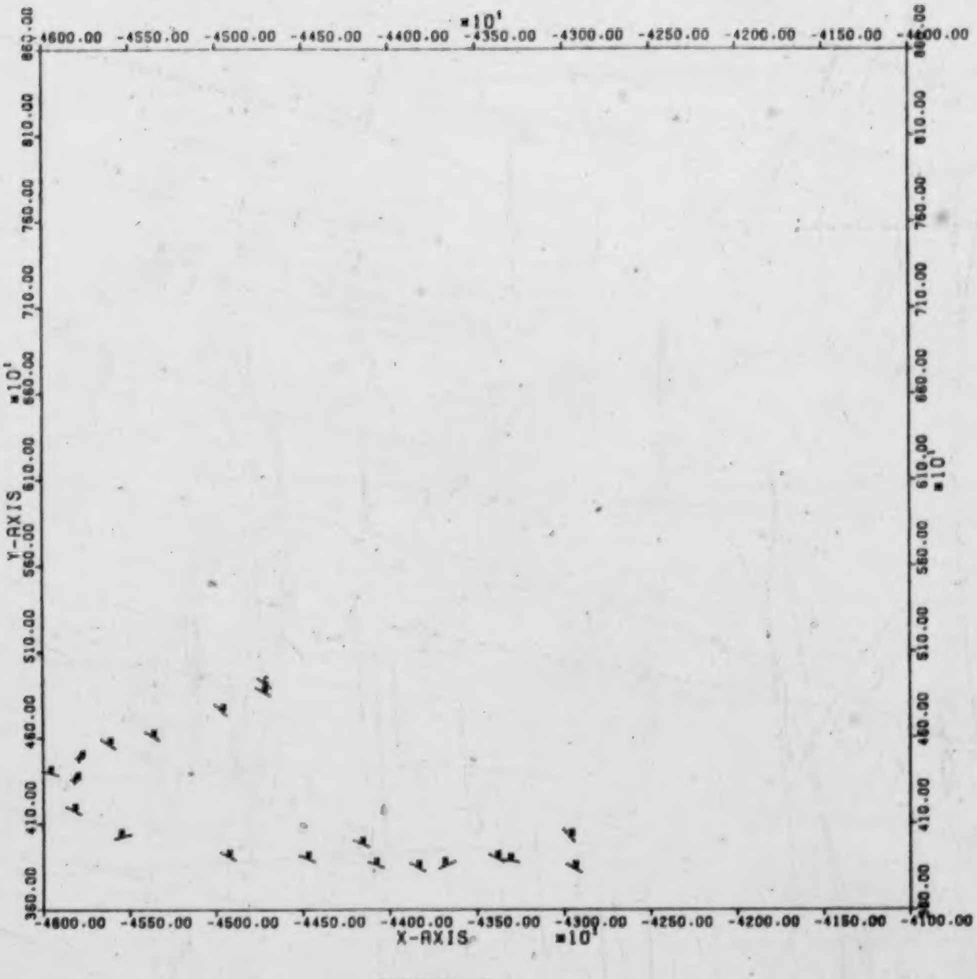
-3920.00
-3850.00
-3780.00
X-AXIS
*10¹
700.00
770.00
840.00
910.00
980.00
1050.00
1120.00
1190.00
1260.00
1330.00
1400.00
*10¹

DOMAIN 14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-4300.00
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-4200.00
-4150.00
-4100.00
X-AXIS
*10¹
Y-AXIS
*10¹
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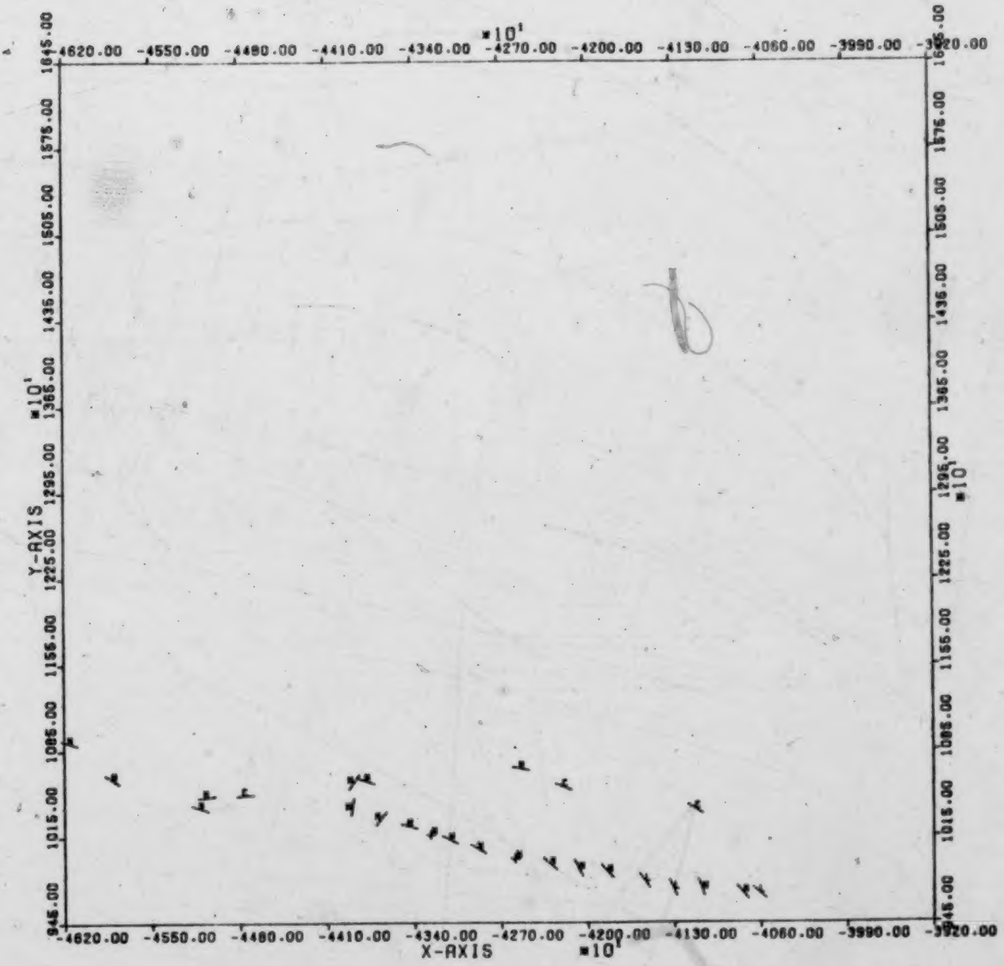
410.00
460.00
510.00
560.00
610.00
660.00
710.00
760.00
810.00
860.00

DOMAIN 15



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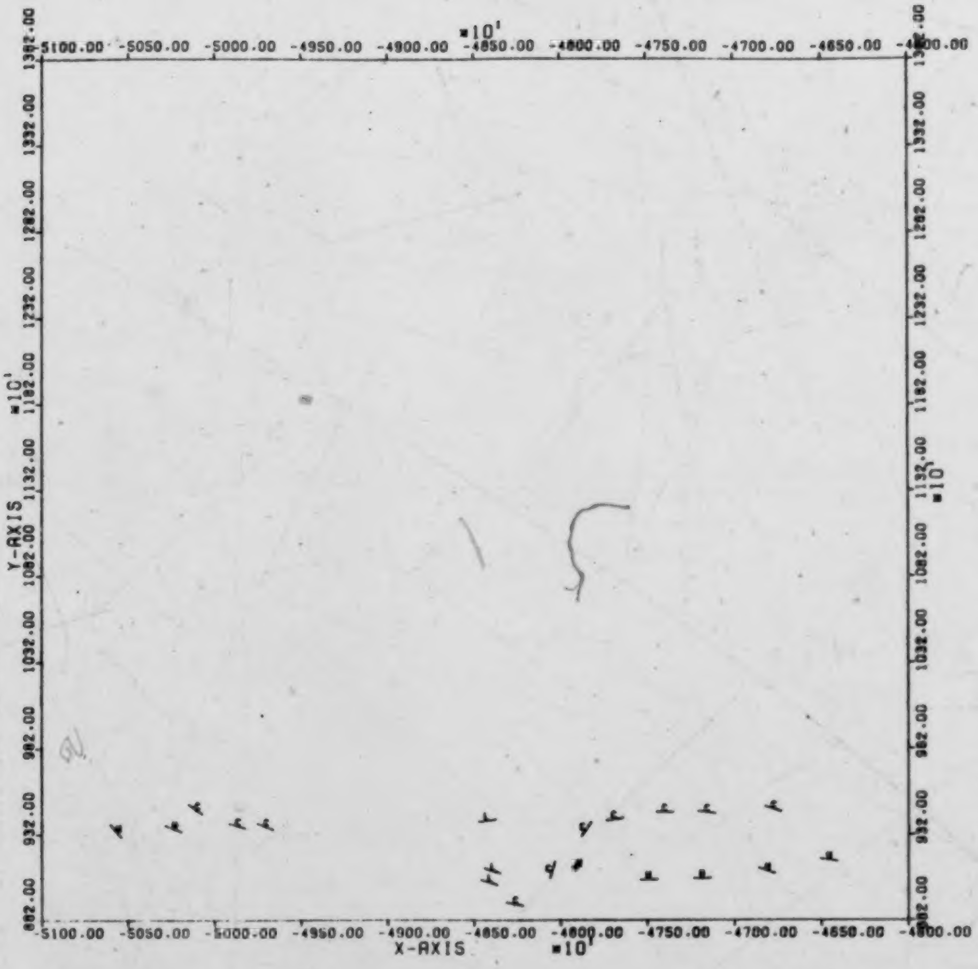
1575.00
1505.00
1435.00
1365.00
1295.00
1225.00
1155.00
1085.00
1015.00
945.00
Y-AXIS
*10¹
X-AXIS
*10¹

DOMAIN 16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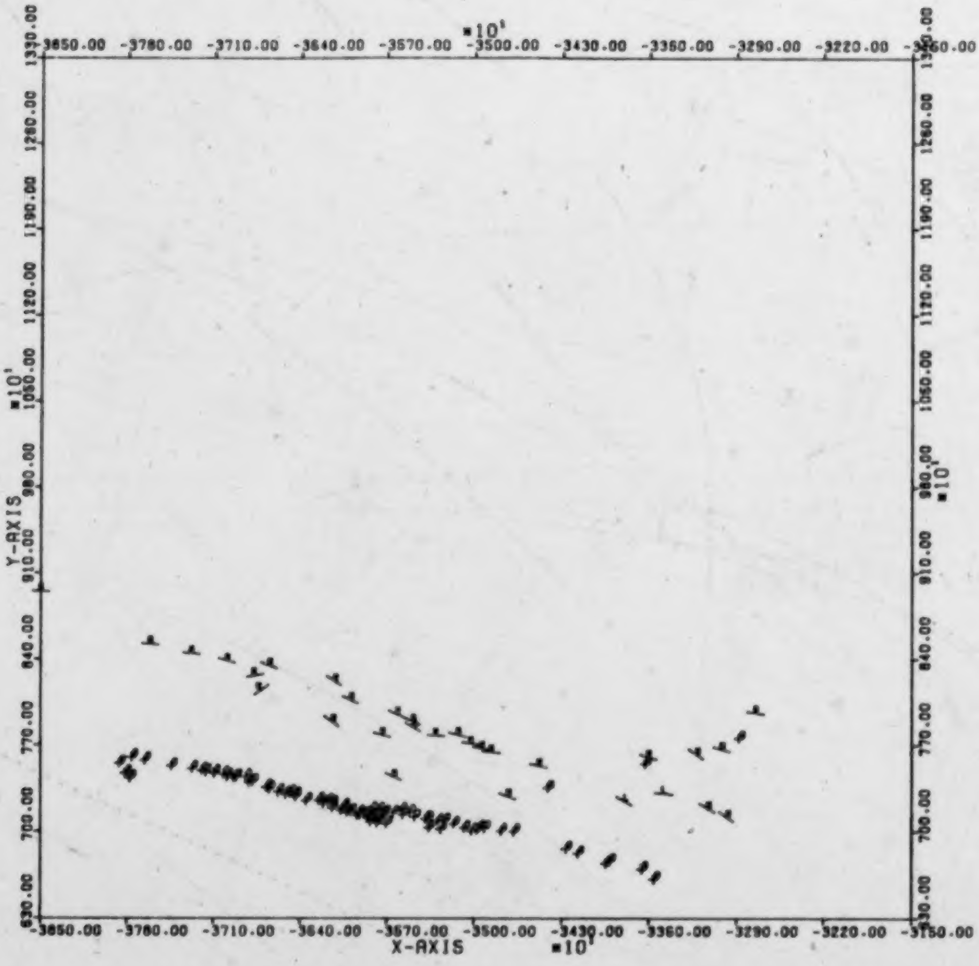
-4700.00
-4650.00
-4600.00
X-AXIS
*10'
Y-AXIS
*10'
882.00
932.00
982.00
1032.00
1082.00
1132.00
1182.00
1232.00
1282.00
1332.00
1382.00

DOMAIN 17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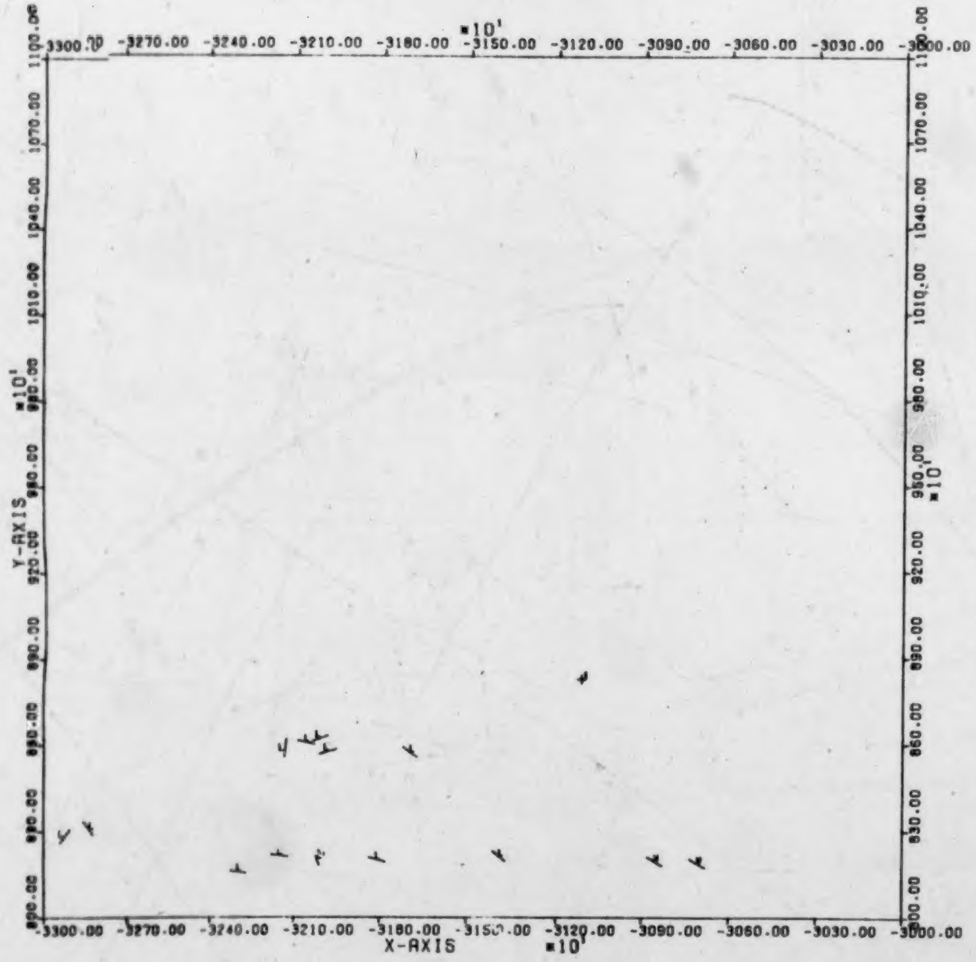
-3500.00
-3430.00
-3360.00
-3290.00
-3220.00
-3150.00
X-AXIS *10¹
Y-AXIS *10¹
630.00
700.00
770.00
840.00
910.00
980.00
1050.00
1120.00
1190.00
1260.00
1330.00
*10¹

DOMAIN 18



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-3120.00
-3090.00
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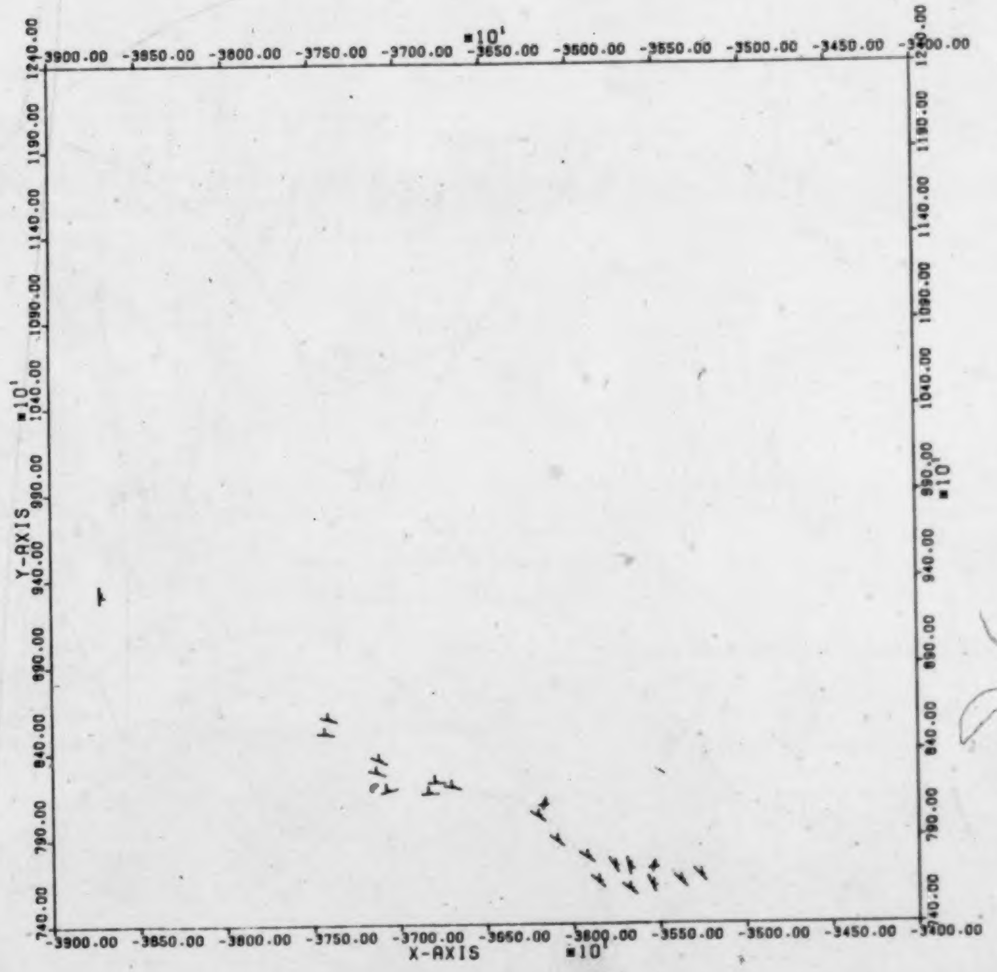
-3030.00
-3000.00
1100.00
1070.00
1040.00
1010.00
980.00
950.00
920.00
890.00
860.00
830.00
800.00
Y-AXIS
*10'
X-AXIS
*10'

DOMAIN 19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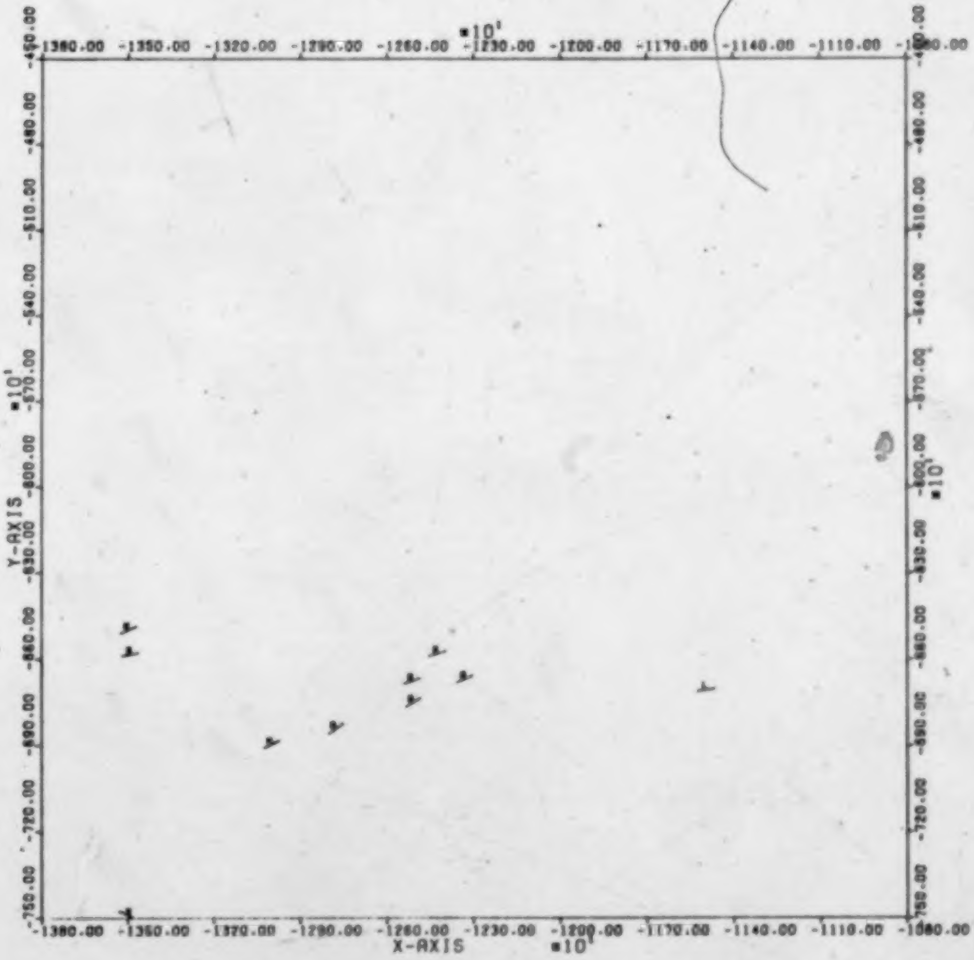
1240.00
1190.00
1140.00
1090.00
1040.00
990.00
940.00
890.00
840.00
790.00
740.00
Y-AXIS
*10'
X-AXIS
*10'

DOMAIN 20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-540.00
-570.00
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-660.00
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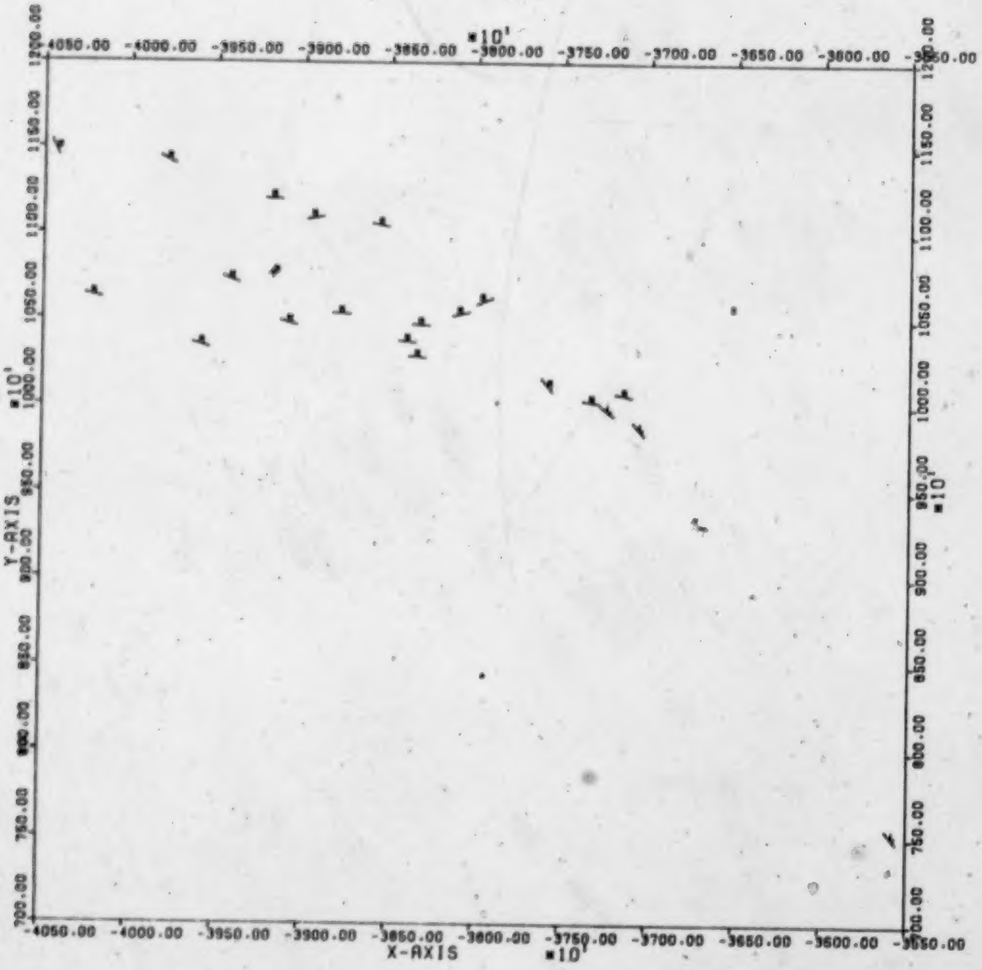
Y-AXIS
*10¹
X-AXIS
*10¹

DOMAIN 21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-3600.00
-3550.00
*10'
X-AXIS
Y-AXIS
700.00
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800.00
850.00
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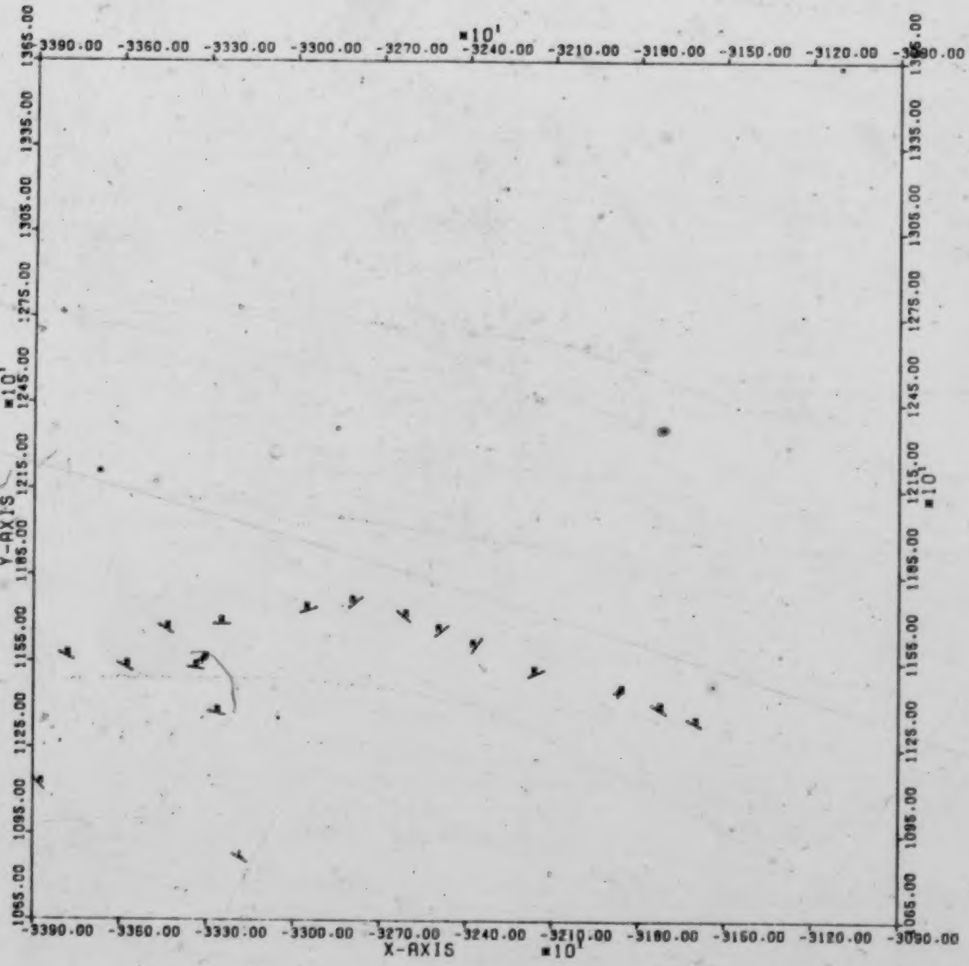
950.00
1000.00
1050.00
1100.00
1150.00
1200.00

DOMAIN 22



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-3210.00
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-3150.00
-3120.00
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X-AXIS
*10'
Y-AXIS
*10'
1065.00
1095.00
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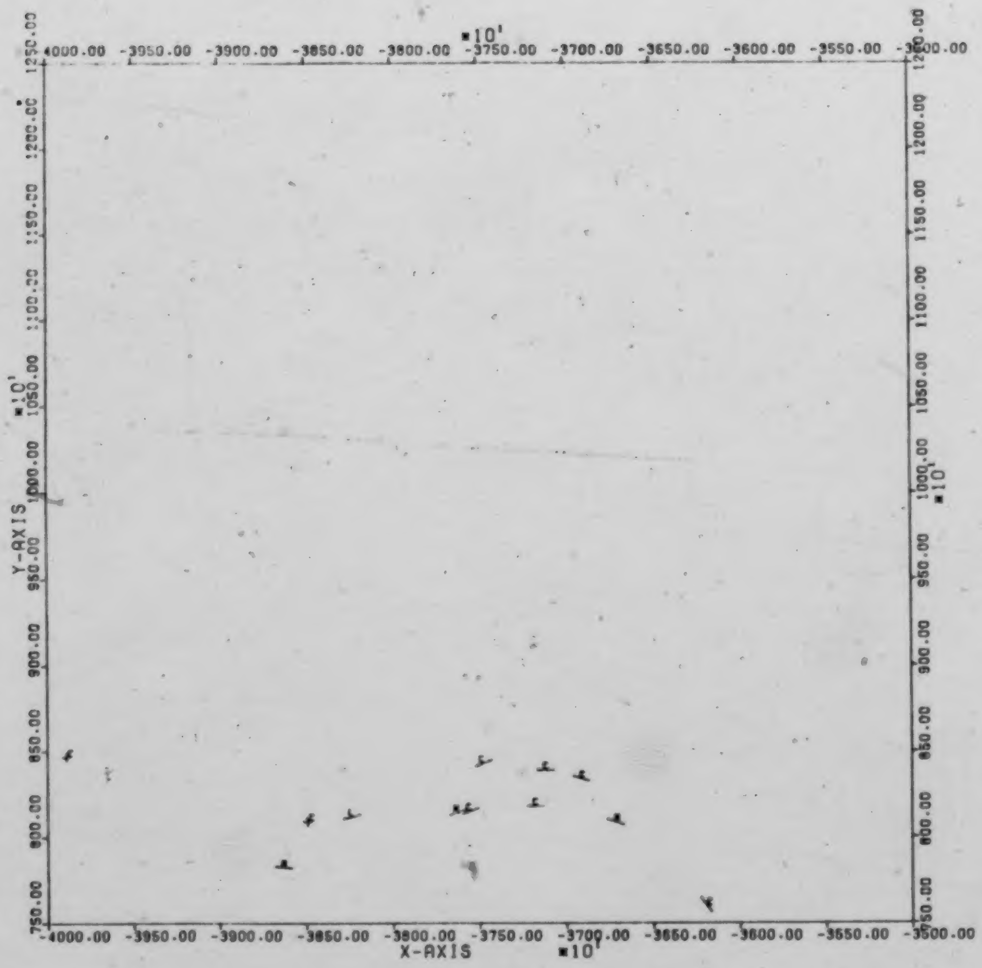
DOMAIN 23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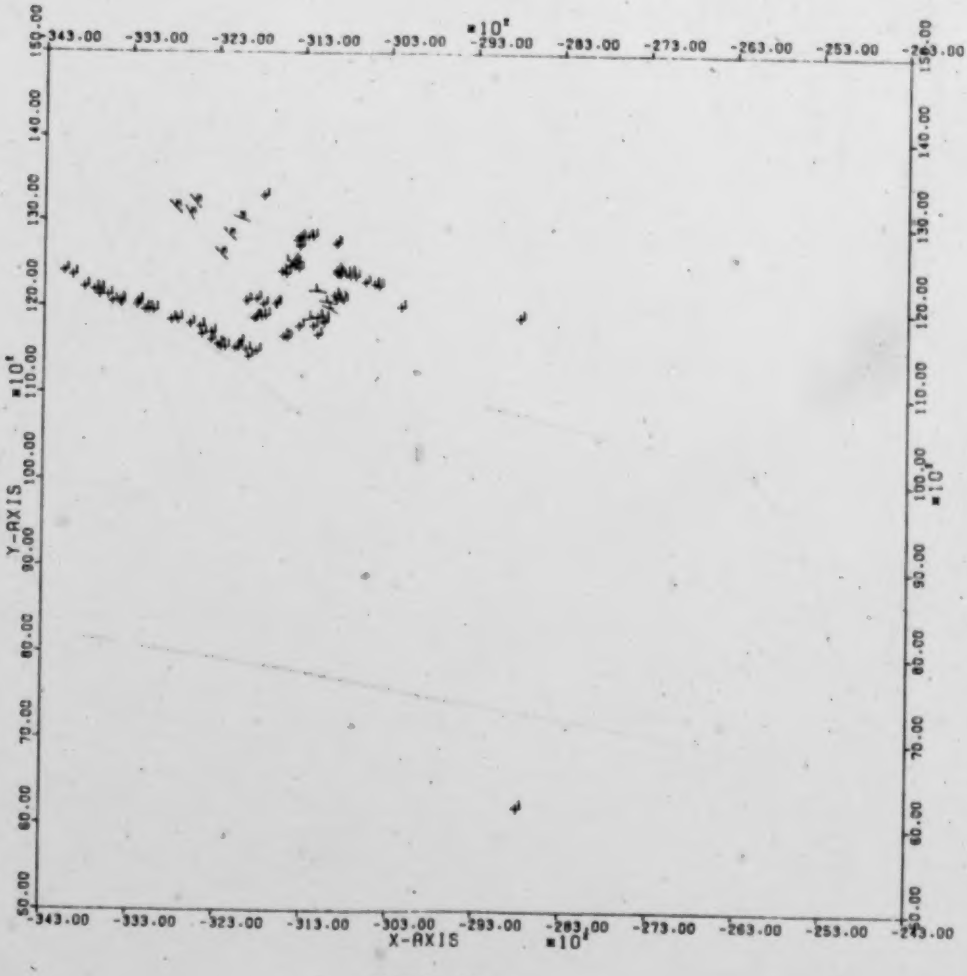
750.00
800.00
850.00
900.00
950.00
1000.00
1050.00
1100.00
1150.00
1200.00
1250.00
Y-AXIS
*10'
X-AXIS
*10'
*10'

DOMAIN 24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140.00
130.00
120.00
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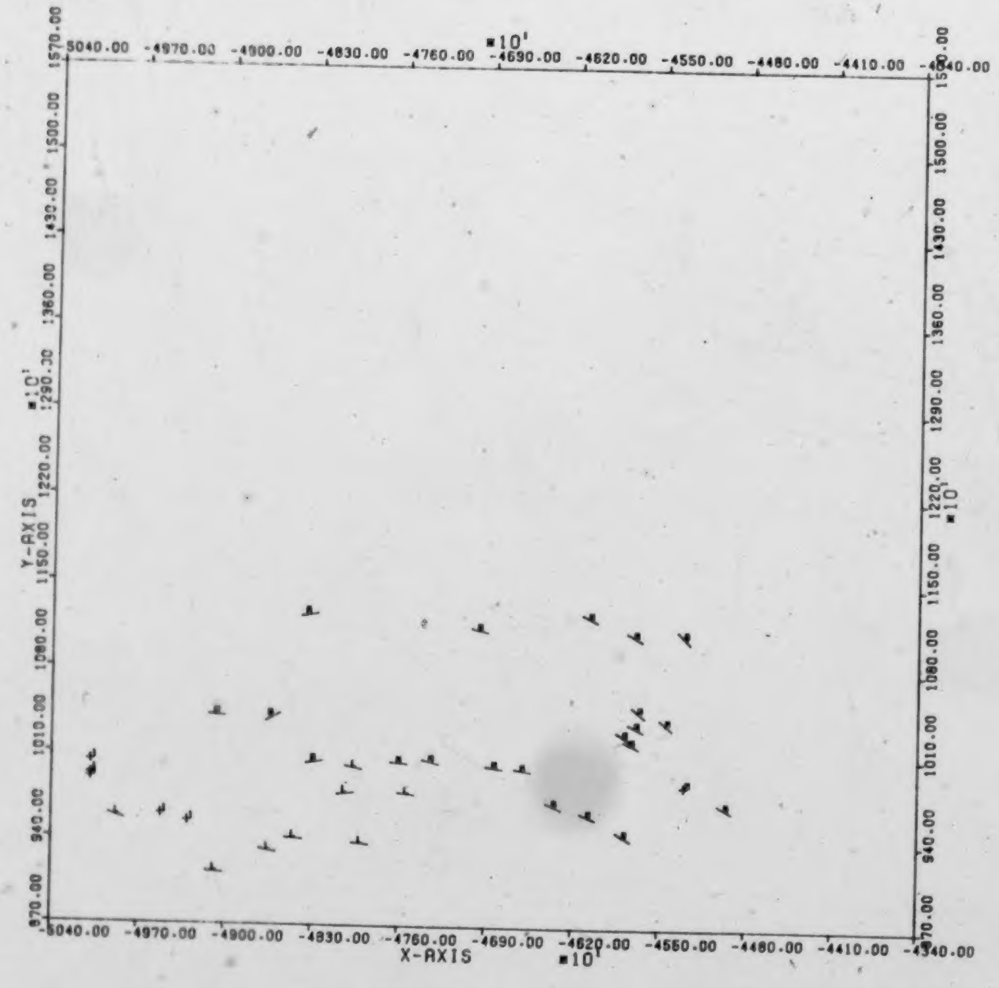
100.00
90.00
80.00
70.00
60.00
50.00
Y-AXIS
*10¹
X-AXIS
*10¹

DOMAIN 25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940.00
1010.00
1080.00
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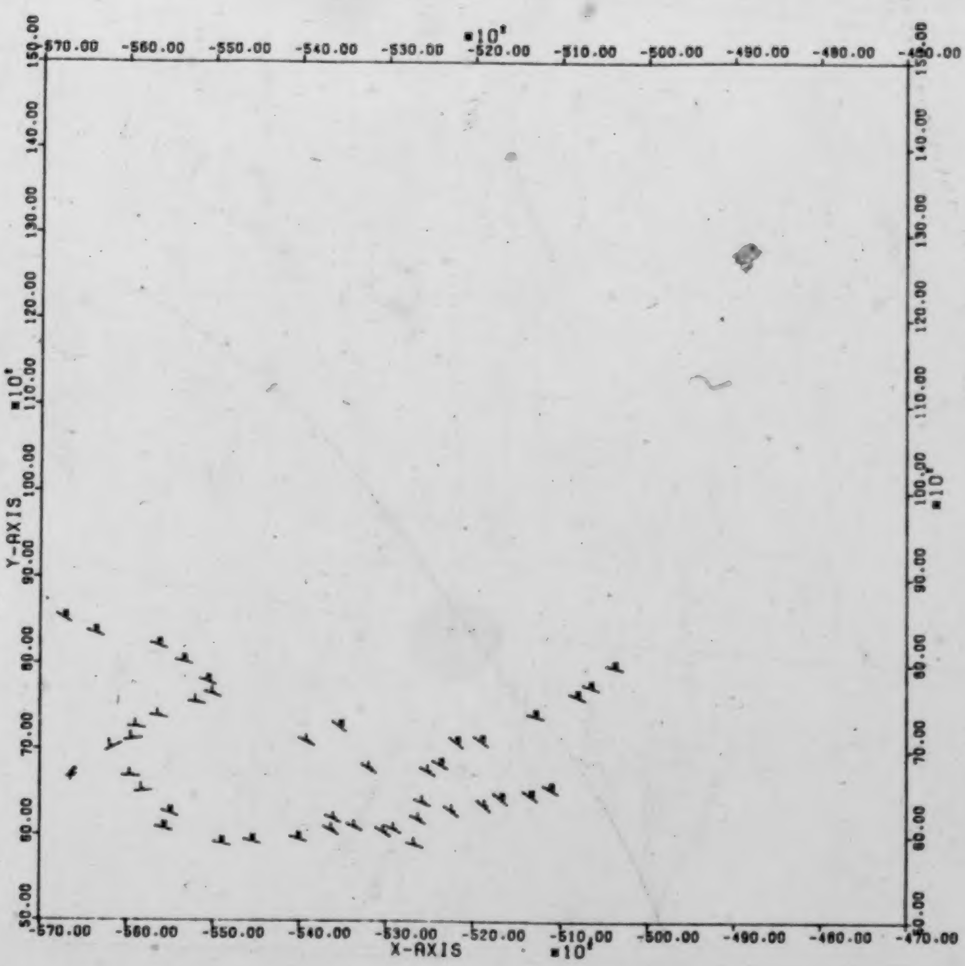
1290.00
1360.00
1430.00
1500.00
1570.00
X-AXIS
Y-AXIS
*10'

DOMAIN 28



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80.00
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100.00
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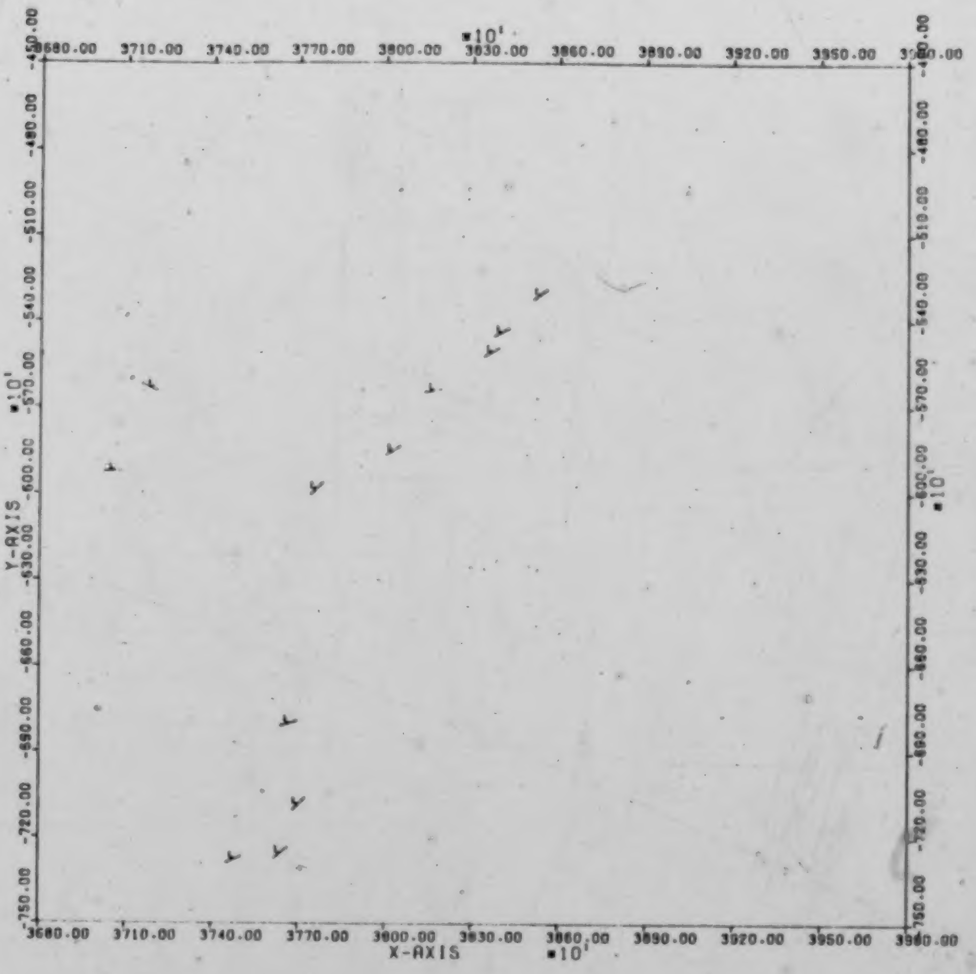
120.00
130.00
140.00
150.00
Y-AXIS
*10¹
X-AXIS
*10¹

DOMAIN 29



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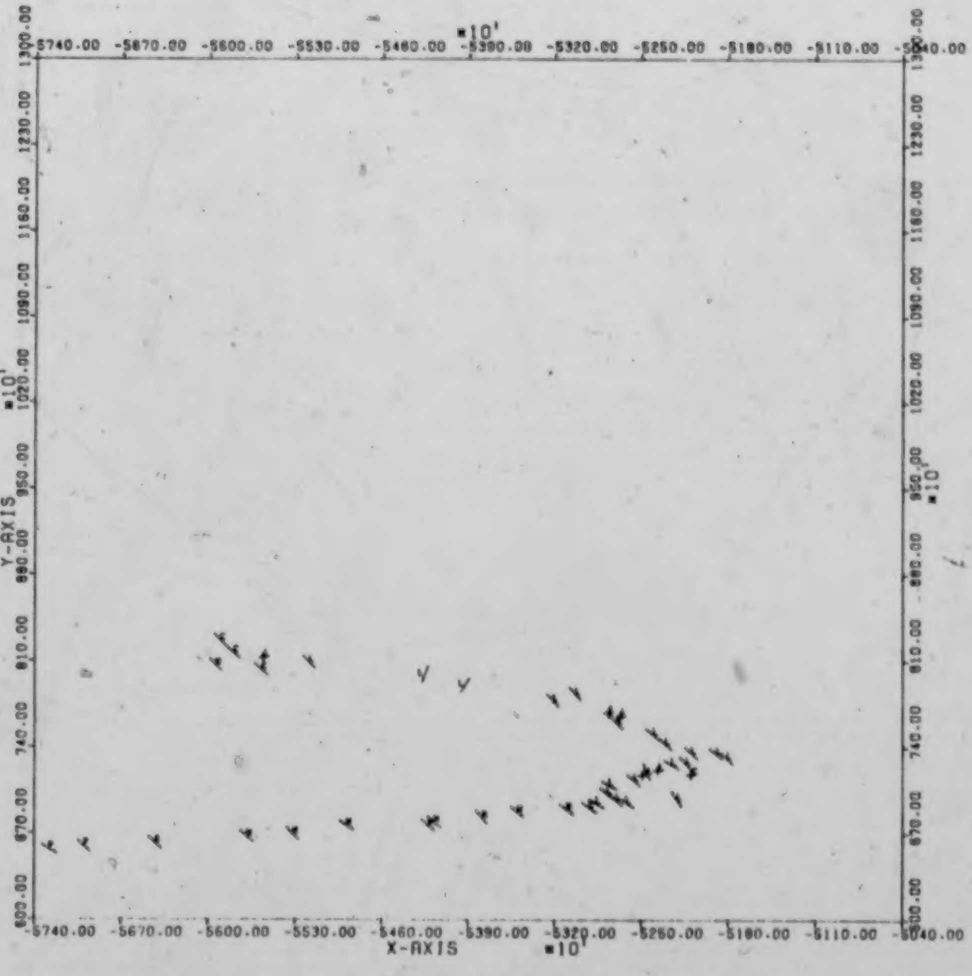
3800.00
3830.00
3860.00
3890.00
3920.00
3950.00
3980.00
X-AXIS
$\times 10^1$
-450.00
-480.00
-510.00
-540.00
-570.00
-600.00
-630.00
-660.00
-690.00
-720.00
-750.00
Y-AXIS
$\times 10^1$

DOMAIN 30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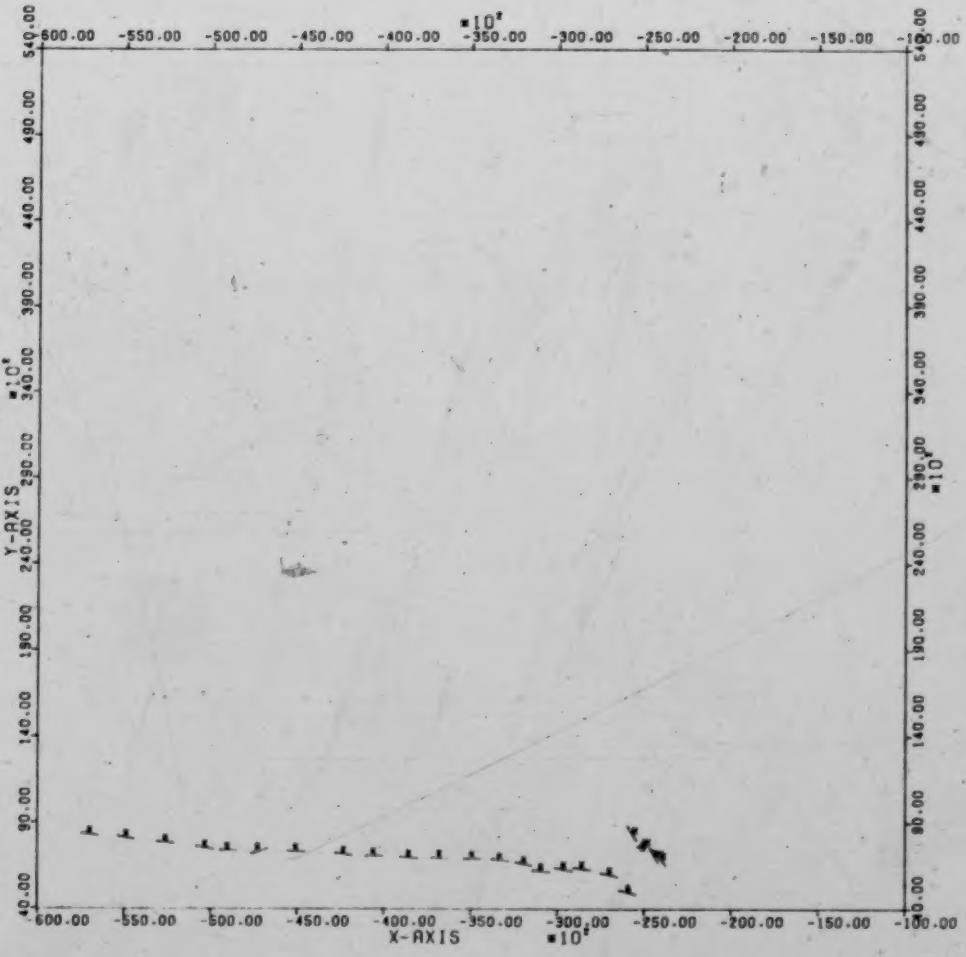
1300.00
1230.00
1160.00
1090.00
1020.00
950.00
880.00
810.00
740.00
670.00
600.00
Y-AXIS
*10'
X-AXIS
*10'
*10'

DOMAIN 31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540.00
490.00
440.00
390.00
340.00
290.00
240.00
190.00
140.00
90.00
40.00
Y-AXIS
*10²
X-AXIS
*10²

DOMAIN 34

APPENDIX 5

Stratigraphic Section Though Part of the Luscar Formation at the Northern end of the West Pit at Mountain Park

Luscar Formation in West Pit

UNIT NO.		Thickness	HEIGHT ABOVE BASE (METERS)
26	Coal seam (Kennedy)...........	5.4	84.7
25	Covered.......................	6.2	79.3
24	Light grey sandstone, very soft due to weathering.......	4.6	73.1
23	Light grey, massive sandstone Trace of Lower Drummond Creek thrust.	4.9	68.5
22	Coal..........................	0.7	63.6
21	Green mudstone with ironstone concretions up to 0.3 m in diameter......................	3.9	62.9
20	Ironstone, ...	0.1	59.0
19	Coaly shale..................	0.1	58.9
18	Olive green mudstone with ironstones...................	1.4	58.8
17	Shaly coal..................	0.5	57.4
16	Grey mudstone................	0.2	56.9
15	Olive green, shaly mudstone, recessive, large ironstone concretions up to 12 cm in diameter.....................	4.6	56.7
14	Brown, green and grey shales, thinnly bedded with iron stains and ironstones........	4.3	52.1
13	Coal.........................	0.2	47.8

UNIT NO.		THICKNESS	HEIGHT ABOVE BASE (METERS)
12	Grey to brown mudstone.......	0.2	47.6
11	Coal.........................	0.1	47.4
10	Black and brown silty shale with ironstone concretions along bedding................	5.8	47.3
9	Grey and brown siltstone platy weathering with cross bedding................	17.6	41.5
8	Black shale grading to grey shale at top.................	2.2	23.9
7	Grey shale, occasional ironstone bed to 5 cm............	5.3	21.7
6	Grey-brown siltstone, red weathering..................	1.3	16.4
5	Light brown to grey shaly mudstone....................	1.4	15.1
4	Coal. (Kennedy)..............	12.7	13.7
3	Sandstone....................	0.3	1.0
2	Coal.........................	0.7	0.7
1	Sandstone....................	0.0	0.0